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Multispectral Imagery Support for Ocean Venture 90

Naval Science Assistance Program
NSAP Task CLF-3-90

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PREFACE

The Naval Oceanographic and Atmospheric Research Laboratory's Mapping, Charting and Geodesy Division performs research and development in new and improved methods for gathering navigational bathymetric data in coastal areas. One area of special interest is the development of algorithms to derive bathymetry from multispectral data. Currently, multispectral imagery can be derived from airborne scanners or from satellite sensors, such as the thematic mapper on board Landsat. Multispectral bathymetry has the potential for gathering data much more rapidly that present shipboard systems; in particular, satellite systems can gather data from many parts of the world that are denied to other collection systems. This report presents the results of applying multispectral bathymetry algorithms and image enhancement and classification techniques developed at NOARL to support a joint amphibious exercise.

EXECUTIVE SUMMARY

The purpose of this Navy Science Assistance Program (NSAP) task was to support fleet amphibious assault forces by providing multispectral imagery (MSI) data for use in the planning and conduct of the exercise Ocean Venture 90 and to determine the usefulness of such products in amphibious warfare. CINCLANTFLT requested NOARL produce a chart based on MSI from LANDSAT thematic mapper (TM) satellite data of the Roosevelt Roads, Puerto Rico and Vieques Island areas for technology demonstration and evaluation by designated operating units.

The development of an MSI chart was divided into three stages. The first stage was to obtain and process raw satellite imagery of the desired operating area. This was done with the ERDAS image processing system using standard image processing procedures along with specially developed techniques. The second stage entailed the production and distribution of a chart suitable for fleet use, along with selected MSI digital tape products which would also be of use to Ocean Venture 90 participants who had access to the appropriate computer equipment. The final stage was the evaluation of the chart and tapes by exercise participants.

The MSI chart was not actually evaluated in the field during the conduct of Ocean Venture 90. However, post-exercise discussions with exercise participants revealed great interest in the potential uses of MSI in operations such as this. Valuable feedback was provided on the products which NOARL had developed, and suggestions were given on what sort of products would better meet their needs. It was agreed upon by all participants that in order for them to gain maximum benefit from MSI, they must have their own capability to perform image processing instead of merely receiving an already processed product from a research laboratory.

The fleet's need for greater application of MSI would be best met by continued interaction between NOARL and operating units. NOARL involvement in another exercise similar to Ocean Venture 90 would serve as an ideal vehicle for further development of MSI products which could be integrated into the fleet.

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BACKGROUND

When planning and conducting amphibious operations, operating forces are often limited by the informational content of their on-hand charts. Depending on the geographic location of the area of interest, the charts may not be up to date, or may not be as detailed as the operational planners desire. Political situations and operational constraints frequently prohibit additional reconnaissance by direct ground observation or aerial photography. Thus, forces are required to perform a mission with a less than complete picture of the area.

This lack of information can be overcome with the use of Multispectral Imagery (MSI) derived from Landsat Thematic Mapper (TM) satellite data. MSI can be processed to provide a wealth of information which could be of use during fleet operations, including the classification of land features and the calculation of water depths in shallow, clear coastal areas. Further, based upon the specific requirements dictated by operational commanders, geographically correct charts for fleet use can be tailored and produced from MSI.

A joint Army/Navy/Air Force/Marine Corps exercise, Ocean Venture 90, was planned for the spring of 1990. It consisted of an airborne assault on selected sites in Puerto Rico, including the Roosevelt Roads area, and an amphibious assault on Vieques Island. CINCLANTFLT requested NOARL produce a chart based on MSI derived from TM satellite data which would be of use during the exercise. The requested product was to be a scaled (1:50,000) chart on a Universal Transverse Mercator (UTM) grid with TM bathymetry and false color infrared (IR) of the Roosevelt Roads, Puerto Rico and Vieques Island areas, and would be produced from the latest available thematic mapper imagery. Designated exercise participants would receive the product for technology concept demonstration and evaluation.

APPROACH

Tasks

Over the past six years, NOARL has developed techniques to exploit satellite and aircraft multispectral digital imagery for naval applications under the sponsorship of Navy Science Assistance Program, Defense Mapping Agency, Oceanographer of the Navy, and the Office of Naval Technology. In particular, specialized image processing computer algorithms to extract water depth information from multispectral imagery have been developed. Other more standard image processing procedures and techniques involving image enhancements, warping to standard map projections and land classification have also been investigated.

The development of an MSI chart was divided into three tasks. The first task was to obtain and process raw satellite imagery of the desired operating area. The second task entailed the production and distribution of a chart suitable for fleet use, along with selected MSI digital tape products which would also be of use to Ocean Venture 90 participants who had access to the appropriate computer equipment. The final task was the evaluation of the chart and tapes by exercise participants. The details of the tasks are described below:

Image Processing

The TM satellite multispectral imagery was processed in the NOARL Mapping, Charting and Geodesy (MC&G) Division Pattern Analysis Laboratory using the ERDAS image processing system. This system consists of a hardware frame buffer image processing board (IMAGRAPH-32) hosted in a COMPAQ 386 IBM compatible PC. A number of image processing peripheral devices are included in the system. The software is a menu driven set of integrated modules incorporating most of the functions needed for image processing. It was developed by ERDAS Inc. of Atlanta, Georgia. NOARL chose to use this system in the preparation of MC&G products to support Ocean Venture 90 because this is the system used by a number of military and naval units participating in the exercise. Brief descriptions of the important routines used in this effort are included in Appendix A. Appendix B contains a detailed discussion of the exact ERDAS processing modules used in each step, along with a description of the resultant digital files. The discussion that follows is a description of the functions necessary to produce the desired results, along with some explanatory material on image processing techniques. In each case the exact ERDAS procedures used are contained in Appendix A and should be referred to by image processing specialists.

In accordance with the specific requirements of CINCLANTFLT, the following steps were conducted to process the imagery:

Georeference image

Rectify to UTM coordinate projection

Overlay UTM grid

Calculate bathymetry

Merge bathymetry with false color IR

Classify land cover and render in pseudo color

Write imagery to digital tapes using ERDAS IMPORT/EXPORT routines for portability to other ERDAS systems

A Landsat TM scene is approximately 100 nautical miles on a side and is divided into four quadrants. The data are delivered on magnetic tape. One 6250 bpi tape contains a quad of seven bands. Figures 1a,b,c show true color renditions of Quads 3 and 4 of the image which was used. These quads were merged into a file, Figure 2, and a sub-area of this was selected for further processing, Figure 3. The latest usable Landsat TM coverage of this area, obtained in October 1989, was ordered but was not received in time to be used for the exercise. Landsat TM scene ID #5032614142 (quadrants 3 and 4) obtained in January 1985 was available at NOARL and was the scene used to prepare the products for the exercise. Two sets (one quad per tape) of these original 7-band digital tapes were copied [see Section B.1, Appendix B] and delivered (PRODUCT 1, Figures 1a,b,c, Table 1) to the designated exercise participants: 2nd TOPO PLT, USMC, Camp Lejeune and 30th ENG BATT, XVIII Airborne Corps, USA, Ft. Bragg. The latest raw digital imagery of the same area, with less than 20% cloud cover, was forwarded to the participants on 7 May 1990 as soon as it was received (PRODUCT 8, Figure 4a,b, Table 1). Color prints representing the digital products and some intermediate steps are included in this report.

Landsat TM Imagery

The original Landsat TM imagery consists of lines of digital numbers (DN's) representing received irradiance reflected from the earth along a corresponding strip of ground (or water). Each line or strip consists of individual DN's corresponding to a small square of about 30 meter x 30 meter. This is a pixel. The data is arranged in band sequential (BSQ) format. The ERDAS software allows the user to conveniently handle the image data as a number of separate spectral band images where the pixels in each spectral band are coregistered. An example of TM bands 1, 2, 3, and 5 is shown in Figures 5 and 5a,b,c,d. When TM bands 1, 2 and 3 are presented on a color monitor with the blue, green and red guns respectively, a "true color" image results as shown in Figure 1. Other band combinations (and monitor gun assignments) result in "false color" images. The assignment of bands 2,5,4:B,G,R results in an image that emphasized the infrared portion of the spectrum and is called false color IR (see Figure 6).

Georeferencing

Because of the geometry of the satellite orbit, the image pixel lines (which are perpendicular to the flight path) and hence the TM images are not oriented in any convenient geographic coordinate system. In order to determine the correct geographic location of each pixel in the image it is necessary to "georeference" the image to a particular geodetic datum. ERDAS has software to facilitate this georeferencing. The general

procedure is to supply the georeferencing module with the geographic coordinates (either latitude/longitude or UTM easting/northing) of a number of widely separated image points. A convenient method for doing this is through the use of a map or chart mounted on a digitizing tablet. After setting up the tablet the cross hair is placed on a map point which can be identified in the image. The image cursor is placed on the corresponding point. This set of points with geographic coordinates (lat-long) and image coordinates (line/element) is input to the georeferencing module which computes transformation functions between the coordinate systems. Care must be taken in georeferencing to ensure that the geographic coordinates used are all on the same geodetic datum and that this is the datum desired for the final chart. For the Ocean Venture 90 charts the North American Datum 1927 (NAD27) was used. Some charts in the Puerto Rico area use the Puerto Rico Datum. If it is necessary to use mixed datums, appropriate transformations must be performed.

Rectification to UTM

For many applications the mathematical transformation between coordinate systems is sufficient. However, for other applications (such as making a chart of the TM image on UTM coordinates which can overlay a map) it is necessary to "warp" or "rectify" the original image into the new projection. Most image processing systems, including ERDAS, do this warp by considering a regular grid on the "output" image. Using the georeferencing transformation equations, the corresponding point is located in the "input" or original image. Normally the point in the input image will not fall exactly on the center of a pixel. The value of the DN which is to be put in the output image is determined by interpolation. Three common interpolation schemes are (1) nearest neighbor, (2) bilinear and (3) cubic convolution. For original imagery the cubic convolution interpolator is normally used. For classified data in which each pixel value refers to a land cover classification (ie, DN = 4 implies "forest", DN = 5 implies "water") the nearest neighbor is the choice. The image scale can be readily changed during the rectification by setting the output grid spacing to the desired value. In doing the warps for this task the output grid was set to 25 meter x 25 meter spacing on a UTM grid. This pixel spacing scale allows an integral number of pixels to be contained in one kilometer and thus permits a conventional metric map scale such as 1:50,000. The details of the georeferencing and rectification of the TM images are covered in Sections B.2 and B.3. Most of the georeferencing control points were chosen to be in the vicinity of Roosevelt Roads and Vieques to minimize the positional errors there. The "before" and "after" images illustrating georeferencing and rectification onto a UTM coordinate system are shown in Figures 3 and 7. It is easy then to add a UTM grid to the resultant image, Figure 8.

Multispectral Bathymetry

Previous research at NOARL funded by the Office of Naval Technology under the Exploratory Development task Coastal Image Understanding (PE 62435N RM035 G85) has investigated techniques for extracting water depth in clear, shallow coastal waters from multispectral imagery. The physical phenomena upon which this is based is the exponential attenuation of light in water and a differential attenuation as a function of wavelength of the light. The model for irradiance received for a single wavelength is given by

$$L = L_s + L_0 R_b e^{-fkd}$$

where L = total irradiance,
L_s = irradiance observed over deep water,
(also written as L_inf, "L at infinite depth")
L_o = constant - function (solar irradiance, atmospheric transmittance, refraction at water surface),
R_b = bottom reflectance,
k = water attenuation coefficient,
f = geometric coefficient to account for path length,
d = water depth.

Only the water depth, d, and the factor f (normally set to 2) are independent of wavelength or color. The above equation can be solved for water depth (d) in terms of the irradiance values and the parameters k and R_b which are not generally known. Current depth algorithms use the functional form of the solution for d and use statistical regression techniques to determine the unknown parameters using water depths known at a few pixel locations in the image. Once these parameters are determined the model can be used to calculate the depths at all points in the image. It has been found that a multiband log-linear model consisting of a weighted sum of single-band solutions:

$$d = A_0 + A_1{}^*X_1 + A_2{}^*X_2 + \ldots + A_n{}^*X_n$$

where A_i = regression model coefficient
$X_i = \ln(L_i - L_{is})$,
ln ( ) is the natural logarithm,
i refers to the i'th spectral band

gave better results than a single-band method. Even more importantly, the multiband algorithm showed little dependence on bottom type [Clark et al (1987)]. This is the bathymetry model used for Ocean Venture 90 products. A three band model was used with TM bands 1, 2 and 3. The known depths at selected control points in the image were obtained by using existing survey data from Defense Mapping Agency charts and from the National Ocean and Atmospheric Administration (NOAA) digital bathymetry data.

ERDAS does not contain multispectral bathymetry modules. NOARL has created routines using the ERDAS supplied Software Toolkit (see B.4 and B.5) to implement the bathymetry calculations. The procedure for creating a bathymetry chart consists of a number of steps. First a file is created for the control points consisting of the position of the point (lat/long or east/west or line/element), the depth of the point, and the TM band irradiance, L_i, values. (Because of the linear calibration of the Landsat TM sensor the DN values from the image can be used without conversion to irradiance units.) It is necessary to have the image georeferenced in order to create this file although rectification is not required. This control point file is used in a statistical regression routine to calculate the model parameters (A_i in the above equation). Once these parameters are determined, a depth value can be calculated for every water pixel in the image using the irradiance values in the image. The resulting bathymetry values can readily be converted into a single band "bathymetry image". ERDAS allows the creation of a color code for the depth values in a "pseudo color" image. A resultant bathymetry image is shown in Figure 9. In this figure striping noise can be seen.

This results from sensor noise in the original TM data and shows up most noticeably in the deeper water where the signal-to-noise ratio is low. In the original bathymetry image produced (and delivered) for Ocean Venture 90 a number of deep water pixels had very low calculated depth values. It was at first thought that this was due to excessive turbidity in the water which can be a serious source of error using these techniques. The region was marked "INVALID BATHYMETRY". Later it was found that the erroneous depths were due to integer overflow in the computer and that the calculated values (in the floating point format) were correct. Corrected charts and tapes were then sent to the participants.

Usually when bathymetry images are calculated, random noise (errors) give the image a "salt and pepper" appearance. Due to the random nature of this noise it is reasonable to post-process the data by applying a smoothing filter using an N x N digital convolution. ERDAS has the capability to accomplish this. However, using a normal 3 x 3 smoothing filter on the data also smooths out sharp edges such as the shoreline and piers. A special filter called a "symmetric-nearest-neighbor" (SNN) which preserves sharp, non-water, edges has been implemented using Toolkit [Miller, et al (1990), Harwood, et al (1987)] (see B.5). Figures 9a,b show full resolution bathymetry "before" and "after" the filtering.

For many image processing procedures in the coastal region, a distinction must be made between land and water. Because infrared radiation does not penetrate water, a very simple land/water classifier can be implemented by a simple threshold detection on an IR band. TM band 5 is typically used for this (see Figures 5 and 5d). Special routines were implemented with Toolkit for the construction of land or water masks based on this procedure, Figure 10. Figures 11 and 12 show the use of these masks. Figure 9 shows an example of a pseudo color bathymetry image with the land masked and the SNN smoothing applied.

Merge bathymetry and false color

An important product specified by CINCLANTFLT for the Ocean Venture 90 support was a combination false color IR image of the land merged with the pseudo color coded bathymetry image. In order to get satisfactory contrast in the false color IR image (land only) combined with the bathymetry, some rather special merging and display function table histogram calculations were required. The details of this are covered in Section B.6. The resultant image is shown in Figure 13.

Land cover identification (classification)

An important advantage in using digital multispectral imagery is the ability to apply powerful clustering and statistical classification algorithms which can provide information to automatically identify land cover types over large areas. (It should be noted that the word "classification" is used in the sense of "identify data elements into classes or types having common characteristics". No security issues are implied.) Statistical classification addresses the problem of assigning data into categories such that all the data points in a class are "similar" to each other and points in different classes are not. An example of classifying coastal images into "land" and "water" has already been given. The algorithm for this was seen to be a simple threshold decision: "if the value of the pixel in band 5 is less than the threshold, assign the pixel to class *water*". Multiband classification is a simple extension of this concept. A geometrical model is quite convenient in discussing the

methods. An n-dimensional space is constructed such that the location of a pixel in this space is given by the n-tuple coordinate (L_1, L_2,..., L_n). A set of M classes is represented by M points, called class centers, in the space. A simple classification algorithm would be to assign a pixel to the class it is closest to (ie. pick the class to minimize the distance between the pixel point and the class center).

It can be seen that for such a classifier to yield useful results, some care should be taken in the definition of the class centers. A common technique is to determine class centers based on training sets. Consider the problem of separating an image into the following classes: "water", "forest", "bare soil". As a first step the operator looks at the image and draws a polygon around a portion that he believes to be "water". The centroid or center of this class is then calculated as the mean value (in a vector sense) of the coordinates of all the pixels in the polygon. This is repeated for the other two classes. The result is three points representing the class centers in our n-dimensional band-space. The classification of the image then proceeds as above, each image pixel is assigned to the class it is closest to in band-space. This procedure is called "supervised classification". The name refers to the fact that the operator or "supervisor" determined the training set which defined the class centers. The constraint on the performance of such a method is the ability of the "supervisor" to properly define the training set. In practice this usually implies the existence of some "ground truth" data that can be identified in the image.

There are a number of interesting variations on this simple scheme. One variation is to insist that a pixel be within a set number of standard deviations of the centroid. If it fails to be in any class, it is put in the class "none of the above". Another variation is to weight the distance measures. A common weight is the variance. A maximum likelihood decision rule is common.

A powerful classification technique is to transform the original data values (pixel band values) into a different set of variables called "features". The purpose of calculating new features is that the resulting "feature space" may allow more sensitive or computationally simpler decision rules. An example of this is the principle component or eigenvector transformation which yields uncorrelated variables.

A slightly different situation is "unsupervised" classification in which the training set for class definition is not predetermined. In this case a number of pixels are randomly selected from the image. A cluster analysis is applied to separate the data into regions where the points bunch together or form clusters. A way to do this is to calculate the distances between all pairs of points. Pick the pair with the minimum distance and merge them into a cluster. Compute the center of the cluster and let it replace the two points. Recompute the distances between pairs (of single points or clusters). Cluster the minimum clusters together. Repeat until all the points and clusters have been reduced to some stopping criteria. A possible stopping criterion could be a predetermined number of clusters. A better criterion might be to stop when the minimum cluster pair distance exceeds a threshold. It is conceptually possible to use all the pixels in an image in a clustering algorithm such as described to do unsupervised classification. However, the computational load grows rapidly with the number of points. A compromise is suggested: use a subsample of the image points to construct a training set through clustering and then use standard statistical classification methods using the clusters to define the classes.

ERDAS contains a number of modules and routines to facilitate both supervised and unsupervised classification of multispectral images. (It should be noted that some other software image processing, statistics, and pattern recognition packages contain a greater variety of classification techniques. However, for most cases the ones in ERDAS suffice.) ERDAS has a very convenient module for classification called ELLIPSE, which produces a 2-dimensional plot of class centers and ellipses of constant variance. For multiple band analysis all pairs of axes can be examined. In order to display the result of a classification, each pixel in an image is assigned a class number (corresponding to the training class). This value is assigned a color which can be selected by the user. An interesting variation is to assign the same color to two separate classes. This effectively merges the classes for display purposes. For example the classes "pine trees" and "oak trees" could be merged into a class "trees". This is convenient when a desired class does not reduce to a simple minimum distance cluster.

A number of land cover classifications were computed on the imagery in the Ocean Venture 90 operations area. The details of these efforts are discussed in Sections B.7 through B.10. The most satisfactory results were obtained with supervised classification. The identification of the classes was based on information found on the Defense Mapping Agency (DMA) combat training chart of Vieques (#806927). An improvement in classification resulted through the use of the "Tasseled Cap" transformation [Crist and Kauth (1986), Crist and Cicone (1984)] before the unsupervised classification. The Tasseled Cap transformation is a special linear band combination transform which has found extensive application in multispectral remote sensing. It is related to the principal component transform although it is fixed and not scene dependent. Its first three resultant components are commonly given the names "brightness", "greenness" and "wetness" which suggest the aspects of the data emphasized. The results of these land cover classifications are shown in Figures 14 and 15. A Tasseled Cap transformation and the resulting unsupervised classification are shown in Figures 16 and 17. Classified images combined with bathymetry are shown in Figures 18 and 19.

A perspective view of Vieques Island with true color imagery overlaid on DMA Digital Terrain Elevation Data was created using the ERDAS 3-D routines. Unfortunately there is a limitation on the image size of 512 x 512 pixels which can be computed by this method. In addition to the small image size, the computation time was excessive (about 30 minutes). The usefulness of the perspective view product should be carefully evaluated prior to extensive use of ERDAS to compute the image. Figure 20 shows the resultant perspective view.

Production and Distribution

A critical factor in preparing products for the exercise was the extremely limited time available to complete the work. CINCLANTFLT requested NSAP assistance on 30 March 1990. NOARL was initially asked by NSAP to submit a proposal for the project on 4 April, and was formally tasked by NSAP to carry through with the effort on 13 April. The deadline date for getting a product in the hands of the users was determined to be 1 May.

The Mapping, Charting, and Geodesy Officer at the United States Atlantic Command provided the primary liaison between NOARL and CINCLANTFLT. He supplied NOARL

with the names of four Ocean Venture 90 participants which would be operating in the Vieques Island area and were potential users of MSI during the exercise:

2nd Topographic Platoon, Camp Lejeune, NC
10th Mountain Division, Ft Drum, NY
82nd Airborne Division, Ft Bragg, NC
XVIII Airborne Corps, Ft Bragg, NC

He particularly desired the 2nd Topographic Platoon (2ND TOPO PLT) to be involved since it is a Marine Corps unit.

When contacted by NOARL, all participants expressed interest in receiving and evaluating MSI products. In addition, the Topographic Engineer at the XVIII Airborne Corps offered the services of the 30th Engineer Battalion (30th ENG BATT) at Ft Bragg to print and reproduce charts from MSI tapes. This offer was accepted, as NOARL did not have a proven method for local production of a chart. Processed imagery tapes (PRODUCTS 1, 2, 4 and 5, Table 1) were sent to the 30th ENG BATT as soon as they were available.

To make the most advantageous use of the time, it was decided to also send processed imagery to the 2nd TOPO PLT. This would give the 2nd TOPO PLT a product in their hands at an earlier date than if they had to wait for a hard copy chart, and would also provide them with the ability to analyze the imagery with their own ERDAS computer image processing system and extract features from the imagery which were of particular interest to them. Unfortunately, the tape drive on their ERDAS suffered a mechanical failure which was not fixed until after the exercise, so they could not take advantage of the processed imagery.

At the same time, a series of delays occurred which ultimately prevented the 30th ENG BATT from printing and reproducing a chart. Difficulty first arose when they were unable to make use of the NOARL supplied imagery tapes because a fault with NOARL's ERDAS EXPORT routine rendered them unreadable. When alerted to the problem, NOARL quickly corrected it and provided them with new, readable tapes, but several days were lost. When the new tapes were received by the 30th ENG BATT, key personnel who had been working with the tapes were away from the unit, thus introducing a delay of several more days. Faced with additional obligations in preparing for Ocean Venture 90, the 30th ENG BATT informed NOARL on 25 April that they would be unable to produce the chart.

Without the printing capabilities of the 30th ENG BATT, NOARL was forced to improvise in order to produce a product for use in the exercise. Using the color printer attached to ERDAS (Tektronix model 4693DX), ten copies of the file COMBO1A.LAN (PRODUCT 5) were printed out at full scale resolution. The resulting chart scale was 1:125,000. Each copy was divided into twelve pages which had to be taped together by hand to make a complete chart. On 26 April, two copies each were express mailed to the XVIII Airborne Corps, the 82nd Airborne Division and the 10th Mountain Division. Four copies were sent to the 2nd TOPO PLT. In addition one copy of supervised land classification of the same area (PRODUCT 6) was sent to each unit.

Evaluation

A questionnaire (Appendix C) was written and sent with the charts to each of the units participating in the product evaluation. It was intended that all users of the chart complete the survey at the conclusion of the exercise. The questionnaire was designed to determine the usefulness of the product in its present form, and to elicit feedback on how it could be improved.

NOARL also hoped to send two observers to the exercise. In addition to carrying additional copies of the chart tc the field, they would monitor the completion of the questionnaires and interact with the users to see first hand the usefulness of the charts and to identify areas for improvement. However, a request to send observers was denied by exercise coordinators. After the exercise, three NOARL personnel visited the 2nd TOPO PLT and 30th ENG BATT to discuss applications of MSI in combat planning and operations.

RESULTS

Field Evaluation

Unanticipated circumstances prevented the evaluation of the MSI chart during the actual conduct of Ocean Venture 90. The scenario of the exercise changed from its original design, resulting in the 2nd TOPO PLT personnel departing for Vieques Island earlier than first expected. Further, the operating area of the Army units was moved away from the vicinity of Vieques Island/ Roosevelt Roads. Thus, the 2nd TOPO PLT did not receive the charts prior to their departure, and the Army units could not use the charts because their operating area was outside of the chart's coverage.

Post-Exercise Evaluation

Upon completion of Ocean Venture 90, three NOARL personnel visited the 2nd TOPO PLT and the 30th ENG BATT. The purpose of the visits was to discuss the exercise and determine whether the products which NOARL had produced would have been of use during the operation. NOARL received additional feedback from participants through the evaluation form which was distributed with the charts. The following observations were made with regard to the chart:

It is very readable. There were no problems understanding it.

It is a good tool for mission planning, terrain analysis, intelligence gathering, and target identification.

A larger scale chart (1:50,000, 1:25,000, 1:12,500) would be of greater value as it would give more detail of the area. The 1:125,000 scale is not a standard scale, and is too small to be of use during ground combat operations.

All of the features which are inherent to TM imagery (identification of vegetation, buildings, roads, water bodies, etc) were found useful.

The inclusion of bathymetry was interesting, but of little use to these participants.

In addition to the specific products (printed chart and digital tapes) that were delivered to the exercise participants, a number of examples in hardcopy prints were discussed with personnel of the 2nd TOPO PLT and 30th ENG BATT during the followup debriefing trip. These exchanges were valuable in illustrating the differing uses that the users have made of the ERDAS system.

There was a strong consensus among the participants that the technology demonstrated by the project has many applications and would be very beneficial in the hands of operating units. They expressed enthusiasm with the prospect of greater exploitation of MSI. However, they also indicated that because of their ever changing roles and the vastly different requirements in various operating areas throughout the world, no single hard copy MSI chart would meet their needs. They would like to be able to

manipulate MSI on their own and produce a chart which would meet their specific needs in any given situation.

CONCLUSIONS/RECOMMENDATIONS

Multispectral imagery has become recognized as a valuable tool in the planning and conduct of military operations. Personnel in all armed services are being trained to understand the benefits of MSI and to operate systems such as the ERDAS image processing system. As the use of MSI becomes more widespread, the potential for innovative applications increases. Operating personnel are seeking ways to make use of the wealth of information available from MSI, but do not have the expertise to undertake ambitious image processing projects. The units which participated in this evaluation were very receptive to NOARL's efforts to provide tnem with new methods of exploiting MSI, and expressed a desire to work with NOARL on related projects in the future.

While this project demonstrated the capability of NOARL to produce MSI products on short notice, the greatest contribution that NOARL can make to advance the use of MSI among operating forces is to provide them with the capability to perform their own analysis and processing of MSI to prepare specialized MC&G products. This can be through the development of specialized ERDAS modules using the Software Toolkit. NOARL has a great deal of expertise in computer programming for image processing applications, and can bring that expertise to bear on fleet analysis objectives through the common use of the ERDAS image processing system. With the ability to process imagery using methods developed by NOARL, units could produce their own products which could be tailored to meet their specific requirements as dictated by operational commanders.

It would be highly beneficial for NOARL to become involved in another exercise such as Ocean Venture 90. This would allow for further development of image processing techniques, and provide NOARL with another opportunity to interact with operating forces. In order to maximize the benefits of the experience, it would be necessary to become involved early in the planning of the exercise, and to spend extended time with the personnel who work with MSI in the units. The ultimate result would the development of techniques by NOARL which could be used by operating forces throughout the Navy and Marine Corps to process imagery.

TABLE 1: PRODUCTS

Delivery	Product	Figure	Description
9 Mar 90	1	1a, 1b, 1c	Raw Puerto Rico TM Imagery Scene ID# 5032614142 Quads 3 & 4 Acquired Jan 1985 Digital Tapes (2ea): Landsat format Files: V3.LAN, V4.LAN
9 Mar 90 Re-submit: 5 Apr 90	2	8	Sub-area mosaic of Prod 1 Quads 3 & 4 6 TM bands (1,2,3,4,5,7), Georeferenced, Rectified to UTM on 25m x 25m grid, Grid and Annotation overlay Digital Tape (1ea): ERDAS EXPORT format File: VSUBR6.LAN
	3	9a	Bathymetry Image of subarea (Prod 2) 3-Band (TM 1,2,3) Regression Model calculated from control points around W. Vieques With Color Code Depth Legend and Annotation Land Blanked. File: VBATH.LAN
9 Apr 90	4	9 9b	Bathymetry, Smoothed, Filtered (3 x 3, Median, SNN) version of Prod 3 File: VBATHF.LAN
9 Apr 90	5	13	Combination Smoothed Bathymetry (Prod 4) in water False Color IR (TM 2,5,4:B,G,R) for Land Digital Tape (1ea): ERDAS EXPORT format Printed, Color, 1:125,000, gridded UTM chart File: COMBO1A.LAN
	6	18	Combination Smoothed Bathymetry (Prod 4) and Pseudocolor Land Classes (6-Band Unsupervised)
26 Apr 90	7	19	Combination Smoothed Bathymetry (Prod 4) and Pseudocolor Land Classes (6-Band,Tasseled Cap transformation, Unsupervised) 8" x 10" Color Print (Scale approx. = 1:400,000)
7 May 90	8	4a,b	Raw Puerto Rico TM Imagery (latest) Scene ID# 4265614171 Quads 3 & 4 Acquired Oct 1989 / With 20% Cloud Cover Digital Tapes (2ea): Landsat format Files: M3.LAN, M4.LAN

Product 5 was corrected and resubmitted 26 April 1990 with Product 7.

LIST OF FIGURES

19. Combination: Smoothed bathymetry and pseudocolor land classes (6-band Tasseled Cap, Unsupervised)

20. 3-D perspective view

21. Principal component transformation (6-band, components 1,2,3 : R,G,B)

REFERENCES

Clark, R. Kent, Temple H. Fay, and Charles L. Walker (1987), "Bathymetry Calculations with Landsat 4 Thematic Mapper Under a Generalized Ratio Assumption", *Applied Optics* Vol 26 No 19, October 1987, pp. 4036-38

Crist, E. P., and R. J. Kauth (1986), "The Tasseled Cap De-Mystified", *Photogrammetric Engineering and Remote Sensing*, Vol. 52, No. 1, Jan 1986, pp. 81-86

Crist, Eric P, and Richard C. Cicone (1984), "Application of the Tasseled Cap concept to simulated Thematic Mapper data", *Photogrammetric Engineering and Remote Sensing*, Vol. 50, No. 3, Mar 1984, pp. 343-352

Harwood, David, Muralidhara Subbarao, Hannu Hakalahti, and Larry S. Davis (1987), "A new class of edge-preserving smoothing filters" *Pattern Recognition Letters* 6 August 1987, pp. 155-162

Miller, H. Vincent, Terri Green-Douglas, Charles L. Walker, R. Kent Clark, Temple Fay, (1990), "Multispectral Bathymetry Programs: A User's Guide" Naval Oceanographic and Atmospheric Research Laboratory Report (in press)

APPENDIX A: ERDAS Routines Used

ALGEBRA - enhances features in a .LAN image by performing algebraic operations on multiple bands of the image data.

ANNOTAT - allows the user to add annotation such as grid lines and numbers, titles, symbols, legends, etc.

BSTATS - used to build a file of statistical information about the contents of a data file. It creates a statistical trailer file (.STA extension) for a .LAN file, or a trailer file (.TRL extension) for a .GIS file.

CLASNAM - allows user to enter or modify class names and descriptions from a .GIS file for each class in the file. The output is a .TRL (GIS trailer) that takes the same root name as the input .GIS file.

CLUSTR - uses the sequential clustering method to cluster data from an input .LAN file. It then uses the minimum distance decision rule to classify the image, based on the clusters created.

COLORMOD - a multi-purpose color selection, modification, and management program. It provides the user with a variety of options to control the colors displayed in the image plane and the overlay plane.

COORDN - computes a transformation matrix, which is used to rectify an image. The transformation may be from 1st to 10th order.

CURSES - used to locate coordinate and pixel information about specific points on the displayed image. These may include screen coordinates, image memory values, function memory (brightness) values, data file (i.e. data base) coordinates for large files, map coordinates for georeferenced files, class names associated with screen values, etc.

DISPLAY - used to display GIS images on the display screen in pseudo color mode. If the file being displayed has a trailer containing a color scheme, that color scheme is used. Otherwise a gray scale is used.

ELLIPSE - allows the user to view graphs of signature statistics, so that signatures can be compared and evaluated. The graphs appear as sets of ellipses. Each ellipse is based on the mean and the standard deviation of one signature in two bands.

EXPORT - used to transfer ERDAS files between computers that run ERDAS software. IMPORT can then be used to read the tape, and convert the files to their original formats.

FIELD - used to select training samples for use in classifying image data. The user interactively selects training samples by outlining the desired area with a polygon on a displayed image file.

GCP - the first step in the registration or rectification process. It creates or modifies files containing ground control points (.GCP extension). A "ground control point" is two sets of coordinates for the same location--one being the data file coordinates of a point in an image file, and the other being the data file or map coordinates

for the same point that references the first point to another image or coordinate system.

IMPORT - used to transfer ERDAS files between computers that run ERDAS software. It reads a tape created by EXPORT and converts the files to their original formats.

LDDATA - allows the user to load image data from tape with flexible control over the loading process. It accepts the following formats: BIL (Band Interleaved by Line), BIP (Band Interleaved by Pixel), or BSQ (Band Sequential).

MAXCLAS- the primary multispectral classification program. It classifies an input .LAN file using one of the following decision rules: minimum distance (spectral distance), Mahalanobis distance, or maximum likelihood/Bayesian.

NRECTIFY - transforms a .LAN or .GIS file to a new coordinate system. This can be done to: (1) project a non-planar image onto a plane (rectification), (2) assign a desired map coordinate system to the image (georeferencing), or (3) make the image conform to another image, so that they can be processed together (registration). It performs rectification from 1st to 10th order. As input NRECTIFY accepts a transformation matrix, which must be previously computed with the COORDN program. It also resamples the pixels in the output image, using nearest neighbor, bilinear interpolation, or cubic convolution.

PRINCE - creates a .LAN file whose bands are the principal components of the bands of an input .LAN file. The output bands are in order from the first principal component band to the last. The variance within the original data will be redistributed so that (1) each band contains nonredundant, independent data, and (2) most of the variance is in band 1, with decreasing amounts in subsequent bands. Principal components analysis is helpful for reducing the number of bands (dimensionality) of the data, especially in preparation for classification.

READ - displays any of the multi-band remote sensing or topographic images in the ERDAS system. The image file to be displayed (.LAN extension) can contain up to eight bands. The user can select up to three of the bands and assign one of the three colors (red, green, or blue) to each band used.

STITCH - used to mosaic (or "stitch together") two or more LAN or GIS files to create a single output file.

STRETCH - maps a .LAN file through function memory, similar to the READ program, and outputs a .LAN file.

SUBSET - copies a selected portion, or subset, of an input data file into an output data file.

WFM - provides a fast, highly interactive method of image enhancement. It allows the user to manipulate the brightness values on the display screen by writing to the lookup tables that are stored in the function memories. WFM performs enhancements on the displayed image

only. It does not change the contents of an image file. However, one can store the lookup tables that are created with WFM to rainbow files (.RNB extension).

ERDAS FILE EXTENSIONS:

.ANT - annotation file.

.GIS - Geographic Information System file.

.GCP - ground control points file.

.LAN - image file with one or more bands.

.RNB - color scheme.

.STA - statistical information about a .LAN file.

.TRL - statistical, class, and color scheme information about a .GIS file.

APPENDIX B: Detailed ERDAS Processing Steps

1. LANDSAT scene ID #5032614142, quadrants 3 and 4, dated January, 1985 was the source of the TM imagery used for this project. LANDSAT imagery of the Puerto Rico area dated October 1989 was ordered commercially from the Earth Observation Satellite Company (EOSAT), but was not received in time for use in this project. (A copy of the October imagery was forwarded to the participants on 7 May 1990.) The 1985 imagery was already on hand at NOARL and was deemed suitable for use. Quadrant 3 contains the eastern part of Puerto Rico including the Roosevelt Roads area, and most of Vieques Island. Quadrant 4 contains the eastern tip of Vieques and the Virgin Islands. Copies of each quadrant (one per tape) were made on the VAX by executing the TAPETAPE program and mailed to Camp Lejeune and Fort Bragg. These copies were termed PRODUCT 1 (Figure 1).

2. A significant problem at this time was a shortage of computer memory, especially since the rectified image to be created later would require even more memory than the unrectified area. Also the combination of quadrants 3 and 4, raw imagery, resulted in a very large file. Therefore, the following steps were taken:

   (1) Using CURSES, determine the starting and ending columns of actual data for each quadrant in order to know which columns to load data into.

   (2) Load quadrant 3 into memory from tape using LDDATA.

   (3) Load quadrant 4 into memory in a file large enough to hold both quadrants, starting quadrant 4 in the correct column.

   (4) Using SUBSET, write quadrant 3 into the file with quadrant 4, without overwriting with input zeroes. (If the option to overwrite with pixels of value zero is selected, valid data in quadrant 4 area will be overwritten with background zeroes from quadrant 3. This is due to the diagonal nature of the quadrants, where they must overlap in order to obtain a mosaic.)

   (5) Since zero values did not get written into the file from step 4 there remained a small area in the first few columns of the file that should have been background zeroes, but were garbage data remaining from when the file was first allocated but not initialized. In order to solve this problem, SUBSET was used again, but this time only writing enough columns from the quadrant 3 file to cover the background area and selecting "yes", that input zeroes should be written. The file containing the 2 quadrant area was called V34.LAN.

   (6) A subarea was defined and written to the file VSUB.LAN using SUBSET.

   (7) Using EXPORT, the file V34.LAN was written to tape and then deleted from memory to make room for further processing.

3. Once a subarea was defined and stored as a file, the next step was to georeference the image to map coordinates. Available combat charts were gathered, and three with

North American Datum 1927 (NAD27) were selected. Other charts utilized various other datums which differed significantly from NAD27 and could not be directly combined with the selected charts. The charts included the complete islands of Vieques and Culebra and surrounding small islands, along with the extreme eastern edge of Puerto Rico around the Roosevelt Roads area. Since chart coverage of the rest of Puerto Rico was not available in the same datum, it was assumed that this area of the image would be less accurate in the rectification.

(1) Using the GCP routine, more than 30 ground control points were selected.

(2) These points were used as input to COORDN to produce a third order transformation matrix.

(3) NRECTIFY was then used to rectify the subarea to UTM coordinates, resampling to 25 x 25 meter pixel size using the "nearest-neighbor" technique. The output from NRECTIFY was the 45 megabyte file called VSUBR6.LAN, which was used in all further applications and products.

(4) The grid and annotation for VSUBR6 was created in the file AV.ANT by the ERDAS ANNOTAT procedure. Each number on the grid had to be entered and positioned by hand and checked against the charts. Titles and chart information were added to the annotation and PRODUCT 2 was completed (Figure 8).

4. The next step involved the computation of water depths from the imagery. The ERDAS Toolkit had to be utilized since there were no bathymetry routines defined as a part of ERDAS. The Toolkit FLECS pre-compiler required Ryan-McFarlan FORTRAN, which had to be installed before continuing. Once this was done, the following steps were taken to compute bathymetry.

(1) The bathymetry algorithms were written in a format acceptable by FLECS and RMFORTRAN, regression coefficients and L_inf's obtained, and a working program called BATHY was created. The program BATHY produced a one band file called VBATH3B.LAN containing the calculated bathymetry.

(2) Using the COLORMOD routine of ERDAS, ranges in the bathymetry image were set to different colors and stored in a color table in \ERDAS73\DATA\COLORS.RNB, entry BATHY.

(3) A color legend was created through the use of ANNOTAT. This image with calculated bathymetry was termed PRODUCT 3 (See Figure 9 and 9a).

5. When the initial computed bathymetry was viewed in color, excess stripe noise inherent in the TM data was apparent, so L_inf's were modified until stripe noise was significantly reduced. There still existed in the bathymetry some error due to computer overflow which led the viewer to see shallow water in an area of known deep water. Because the cause of this error was not known at the time, the area was

blanked out using ANNOTAT to draw a polygon and declared to be "invalid bathymetry". This file was called VCUT3B2.LAN.

(1) A smoothing filter was applied to the bathymetry data to reduce local "salt and pepper" random variations. ERDAS is equipped with several filters, but none preserved sharp edges such as the coastline on the image. A "symmetric-nearest neighbor" (SNN) filter had been used in the past and produced favorable results, so a Toolkit program called FILTER was written which employed this technique.

(2) Various size and type SNN filters were tested by this program and a 3 x 3 median filter was chosen. Using this filter, the program FILTER produced a filtered bathymetry file, VCUT3B2F.LAN.

(3) The file was combined with the color table, legend, and grid from previous products to produce PRODUCT 4 (Figure 9).

6. The next step involved combining PRODUCT 4 with a compilation of bands 4, 5, and 2 for red, green, and blue over land areas.

(1) VSUBR6.LAN was read to the screen in bands 4, 5, 2 with a .STA file created over a small land area.

(2) After the image was read to the screen with satisfactory colors, the ERDAS routine STRETCH was called to store this brightness histogram stretched image with values ranging from 0 to 255 in a file called VSTRETCH.LAN. This was necessary because the bathymetry was stored in that range and if both files were to be combined and read later, the ranges had to be the same in order to obtain the original colors.

(3) Next, a program COMBINE was written to read in the two input files, determine whether a pixel was land or water, and output a 3 band file. The 1 band bathymetry image had to have each color read as a combination of red, green, and blue and written out as 3 bands since VSTRETCH required 3 bands. This was accomplished by reading the .RNB file for the BATHY color combinations and using those values for each bathymetry range.

(4) Finally, the legend and grid from previous products was added and PRODUCT 5 (Figure 13) was completed.

7. Steps were taken to produce an identification of various land features in the image using statistical classification procedures.

(1) Unsupervised classification through the use of the ERDAS CLUSTR routine was performed on the image with unsatisfactory results.

(2) Varying the cluster sizes and maximum number of clusters resulted in minimal improvement.

(3) Another avenue of approach was to mask out all the water pixels by writing a routine MASKW with the ERDAS Toolkit, and running this program to produce an image with only land, then performing unsupervised classification on the land-only image using all 6 bands and 14 classes. There still was not much variation; clusters were either very large and covered a variety of land types or too small to be seen. However this would be used as the land input for PRODUCT 6.

(4) COLORMOD was used to assign colors to the classes and hardcopies produced.

(5) The program COMBINE2 was written using the ERDAS Toolkit, which combined the unsupervised land classification with calculated bathymetry resulting in PRODUCT 6.

(6) Another program, MASKL, was written to mask out the land areas so that classification on water only could be performed, with land and water later combined, but work in this area was discontinued in favor of pursuing supervised classification.

8. A subset of the image, including the complete island of Vieques and surrounding water only, was used to conduct supervised classification.

(1) This was accomplished by selecting training samples of the image and calculating statistical signatures for each sample with the ERDAS routine FIELD.

(2) ELLIPSE was called to graphically plot the signatures for analysis.

(3) Selecting appropriate training samples was difficult, but after defining and discarding many samples, the ERDAS MAXCLAS routine was called to classify the image, producing favorable results.

Because of the lack of "ground truth" information available, there was no way to ascertain the correctness of the classification. It did appear to be representative of the area based on the land descriptions on the charts.

9. In an effort to extract further information from the image, various ERDAS routines were called and results evaluated.

(1) Within the ALGEBRA module, the transformations RGB2IHS (red, green, blue to intensity, hue, saturation) and IHS2RGB were executed.

(2) PRINCE was called to perform a principal components transformation on the image. These transforms yielded little additional information for this exercise (Figure 21).

(3) A three-dimensional image was created by overlaying the imagery on Digital Terrain Elevation Data using ERDAS's 3-D routines. There was a 512

x 512 size limitation for this procedure, which was not adequate for the area in question, so only a small area of western Vieques was made into 3-D. Even this small area required much computer time to run and produced an image of questionable value. ERDAS is not the ideal software package to use for 3-D visual applications.

(4) Various other routines and image enhancement techniques were exercised. Their results offered much insight, but did not lead to the development of a product which would be of use to exercise units.

10. A Tasseled-Cap transformation, a specialized principal components type transformation which extracts features of "brightness", "greenness", and "moisture", was performed on the image.

(1) Since a 6 x 6 matrix was available in the literature for a 6-band TM transformation, it was programmed into the ERDAS ALGEBRA routine directly as an option. This transformation produced favorable results, particularly when the function memories were altered to enhance the contrast.

(2) The ability of the Tasseled-Cap transformation to extract additional information from an image was demonstrated when unsupervised classification was performed on the Tasseled-Cap image file TASCAP.LAN using CLUSTR. The resulting image was a noticeable improvement over the land classification of the original image.

(3) A color table was created for this file, TASCAP.GIS, and stored in the trailer using COLORMOD, and names were assigned to the classes as best as possible from the available ground truth with the routine CLASNAM.

(4) The program COMBINE2, used in the creation of PRODUCT 6, was utilized again with TASCAP.GIS and bathymetry as inputs to create PRODUCT 7 (Figure 19).

(5) ANNOTAT was used to add a grid, legend, and other annotation for PRODUCT 7 (Figure 19).

APPENDIX C: QUESTIONNAIRE

26 APRIL 1990

The enclosed MSI charts were developed by the Naval Oceanographic and Atmospheric Research Laboratory (NOARL) specifically for Ocean Venture 90. Your unit has been selected to receive the charts in order to field test and evaluate them during the exercise. Consider the charts an additional tool, and try to use them as much as possible during the exercise. Allow as many men as possible to use the charts, as well. **It must be emphasized, though, that for the sake of operational safety, these charts should not be relied upon to the exclusion of your conventional charts.**

Attached are evaluation forms to be completed at the conclusion of Ocean Venture 90. Please have all men who have <u>any</u> contact with the MSI chart complete an evaluation. If necessary, make additional copies. Emphasize to them the importance of providing constructive feedback. We at NOARL won't know how to improve the chart if the people who actually use it don't tell us what needs to be improved.

Forward the completed evaluations to:

LT DAVID BYMAN
NOARL
CODE 351
STENNIS SPACE CENTER, MS 39529-5004

Refer any questions to LT Byman at (Comm) 601-688-4878 or (AV) 485-4878, or to Dr. Charles Walker at (AV) 485-4608. Your assistance is appreciated.

DA Byman

D. A. BYMAN, LT USN
NOARL CODE 351

MSI CHART EVALUATION

NAME (optional)______________________________________

UNIT____

RATING/SPECIALTY/RANK_______________________________

YEARS IN THE SERVICE___________

The multispectral imagery (MSI) chart which you used during Ocean Venture 90 was developed by the scientists at the Naval Oceanographic and Atmospheric Research Laboratory (NOARL). However, **YOU** are the real expert about what kind of chart would be of the most use to the military during an operation such as Ocean Venture. Please take the time to complete the following evaluation in order to provide NOARL with feedback as to how the MSI chart can be improved in the future. <u>Comments are especially welcome and desired</u>.

1. The MSI chart was produced using LANDSAT (satellite) imagery. How much experience have you had using LANDSAT imagery?

( ) None. I had never used it prior to this exercise.
( ) Occasional use.
( ) Frequent use.
( ) Extensive use. It is a regular part of my work.

2. How much did you use the MSI chart during Ocean Venture 90?

( ) Occasionally.
( ) Frequently.
( ) I used it every time that I used a conventional chart of Vieques.

3. Is the chart readable? Could a person with your experience level easily understand it? What did you find confusing?

4. Rate the usefulness of this chart for each of the functions listed below.

		Very Useful	Somewhat Useful	Not Useful	Don't Know
( )	Mission Planning	( )	( )	( )	( )
( )	Terrain Familiarization	( )	( )	( )	( )
( )	Intelligence	( )	( )	( )	( )
( )	Target Identification	( )	( )	( )	( )
( )	Weapon Delivery (Air)	( )	( )	( )	( )
( )	NGFS	( )	( )	( )	( )
( )	Mine Warfare	( )	( )	( )	( )
( )	Amphibious Operations	( )	( )	( )	( )
( )	Special Operations	( )	( )	( )	( )
( )	Surface Navigation	( )	( )	( )	( )

Place an **X** to the left of the functions for which you actually used the chart in this exercise.

Comments:

5. Which features of the chart did you find useful?

( ) Location of vegetation
( ) Location of water bodies
( ) Location of roads
( ) Location of buildings and other cultural features
( ) Location of landing zones
( ) Location of shoal areas
( ) Water depths
( ) Topography
( ) Beach widths
( ) UTM grid
( ) Others (list below)

6. What additional features should be added or enhanced to make this a more useful product? Why are these features needed?

7. Did you find any differences between this chart and the conventional charts you were using (UTM grid, water depths, shoreline definition, location of man-made objects, etc)? Where?

8. Did you find any differences when comparing this chart to the actual geographic features of Vieques (water depths, shoreline definition, location of man-made objects, etc)? Where?

9. If you could have a chart like this on a future operation, would you want it? Why or why not?

10. Do you have any other comments or suggestions about this chart? (Remember, without your feedback, NOARL will not know how to improve the chart in the future.)

IF YOUR JOB INVOLVES:

(a) WORKING WITH ERDAS, OR

(b) PLANNING FOR OPERATIONS SUCH AS OCEAN VENTURE 90,

PLEASE CONTINUE THIS EVALUATION. <u>IF NOT, YOU MAY STOP HERE.</u>

FOR ERDAS USERS AND OPERATION PLANNERS ONLY:

This chart was developed by NOARL using specialized image processing algorithms to extract water depth information from multispectral imagery, and by using other more standard image processing procedures and techniques involving image enhancements and warping to standard map projections. One possible application of this project is the improvement and distribution of these algorithms to topographic units. Then, using their facilities, the units could process imagery to meet the specific needs of operational commanders and produce a georeferenced image in the form of a digital (soft copy) chart. This processed imagery could be used alone, or could be used to print a hard copy chart.

11. Would you like for topographic units to have the capability to process raw LANDSAT imagery on short notice to produce a georeferenced image such as this chart? Why or why not?

12. One advantage of a soft copy chart over a hard copy chart is the ease with which it can be manipulated and changed to extract and highlight various features of interest. Do operation planners have access to facilities which would allow them to analyze digital data in preparation for an impending operation? How useful would a soft copy chart be to planners?

13. Do you think that pre-printed hard copy MSI charts of selected areas would serve any useful purpose to the military? If so, who should have them on hand?

14. Do you have any other comments or suggestions which have not been addressed? (Continue on back)

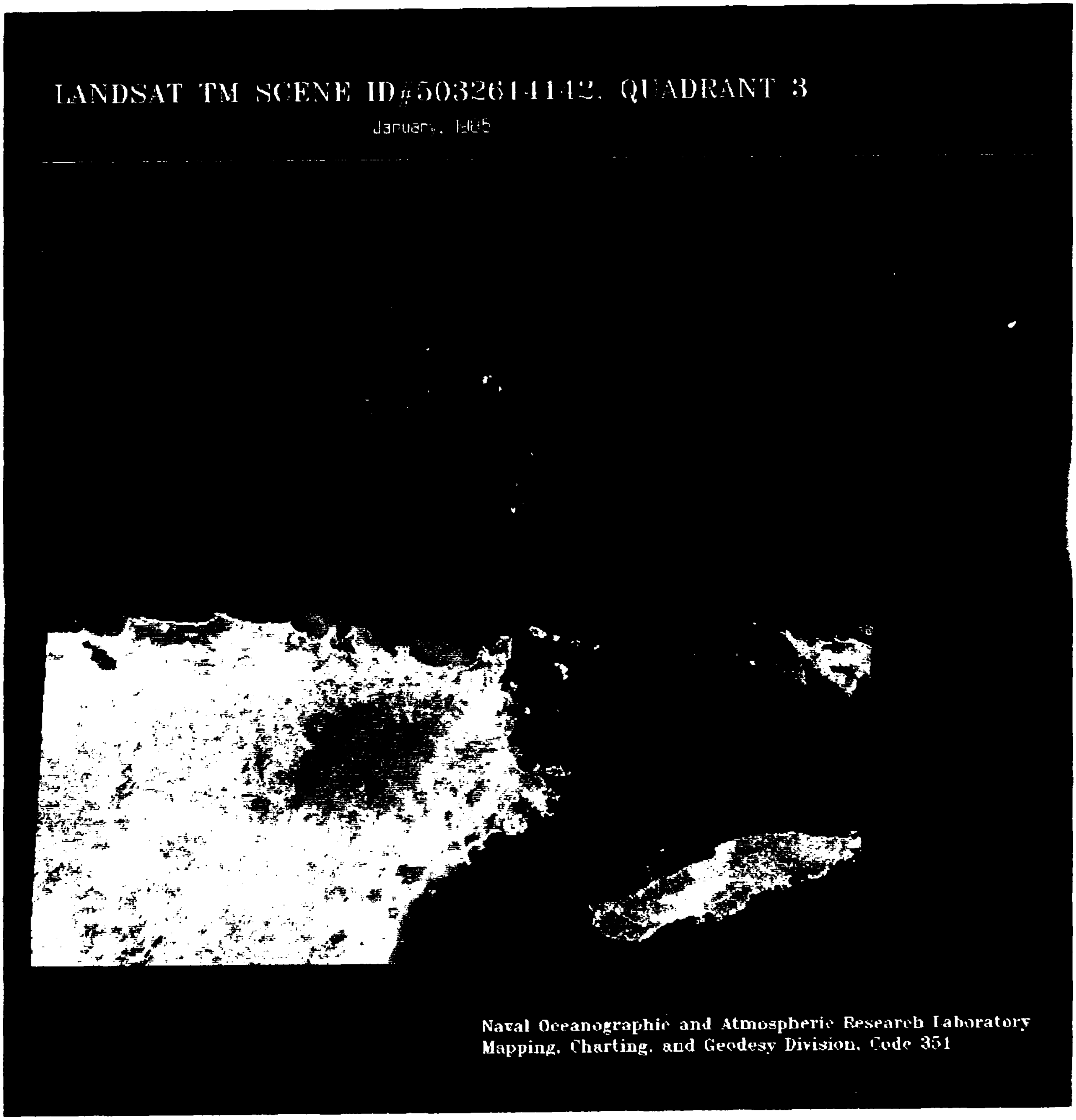


Figure 1a. Landsat TM scene ID#5032614142, quadrant 3, January 1985

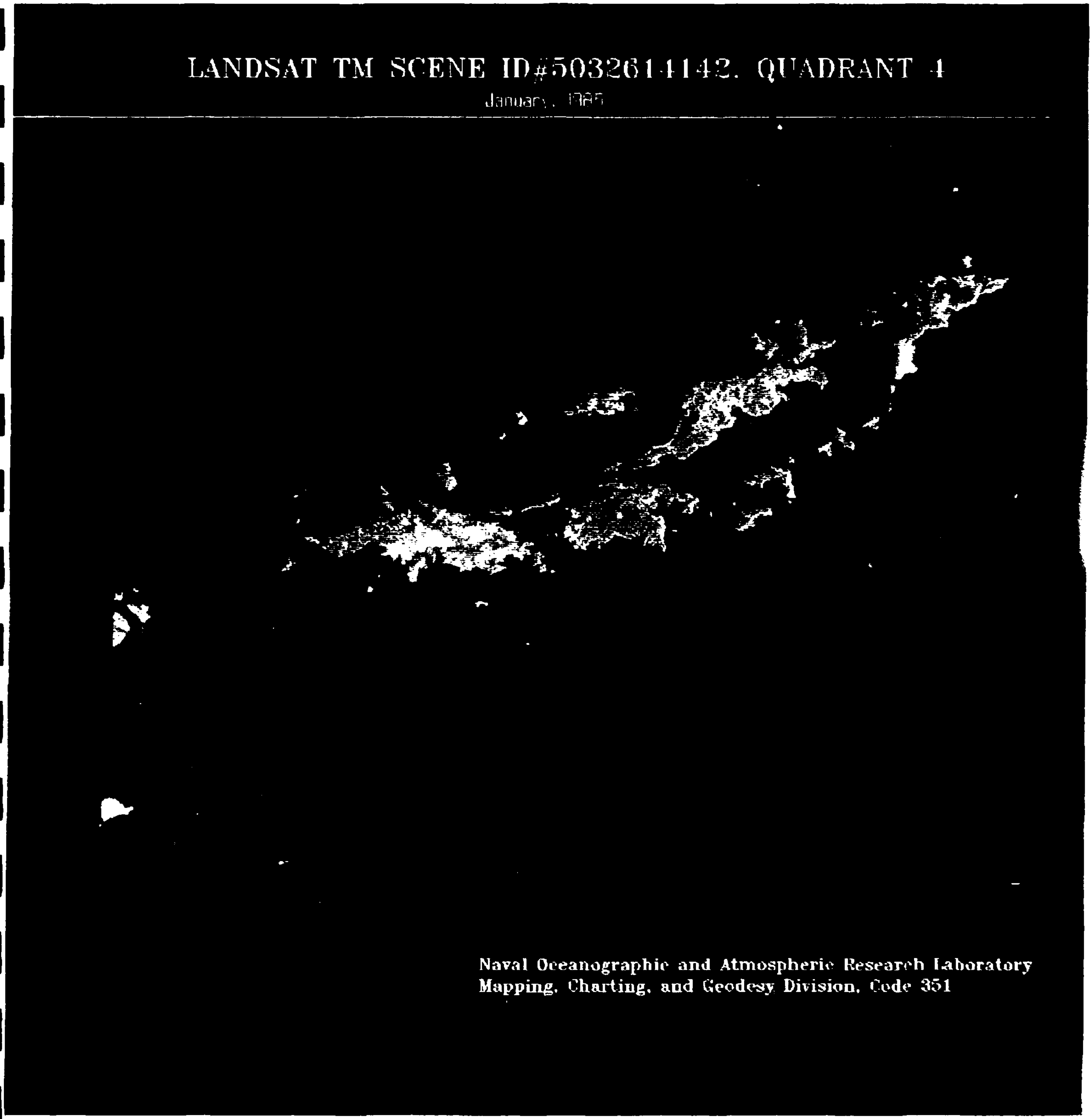


Figure 1b. Landsat TM scene ID#5032614142, quadrant 4, January 1985

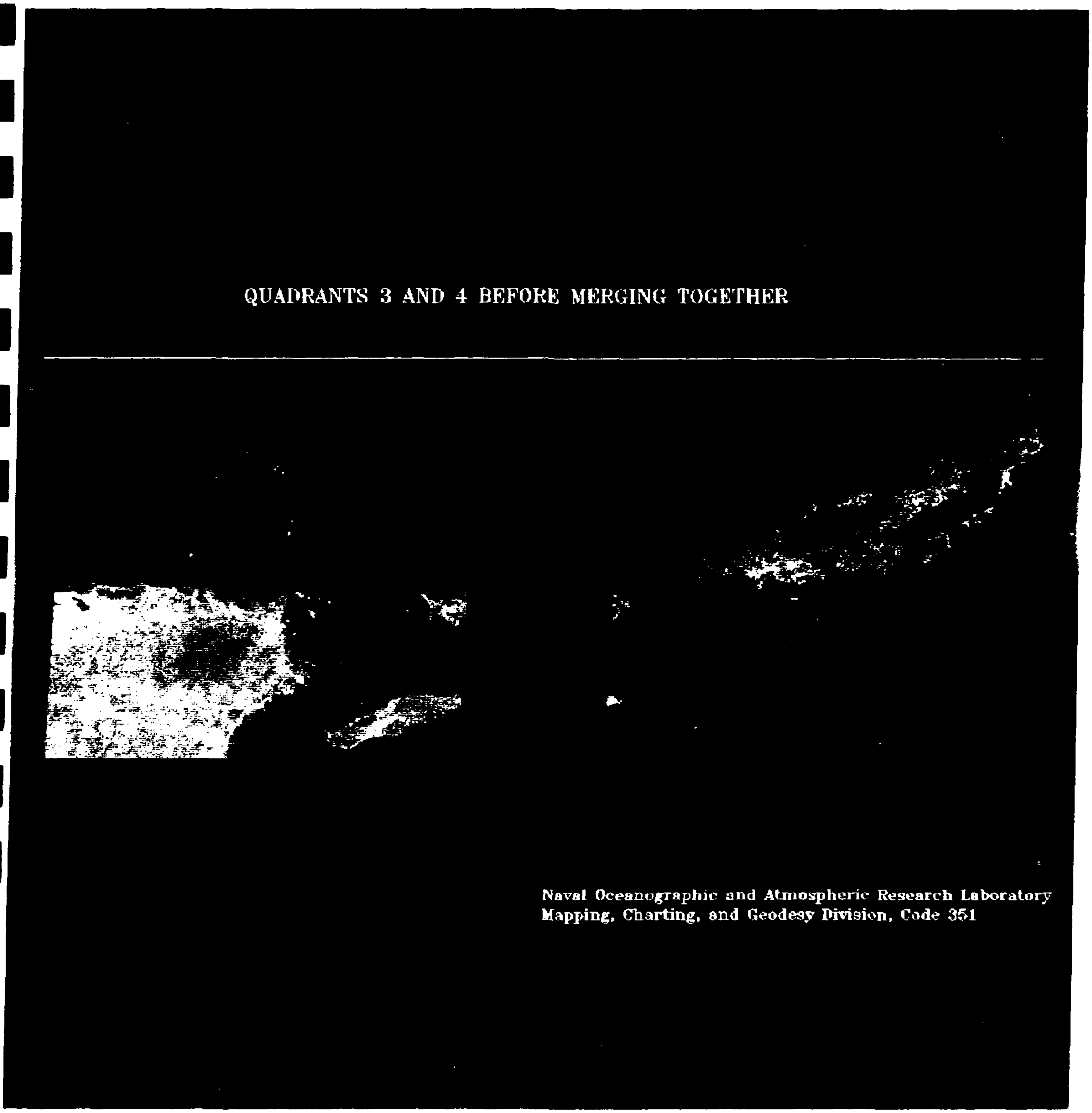


Figure 1c. Quadrants 3 and 4 before merging

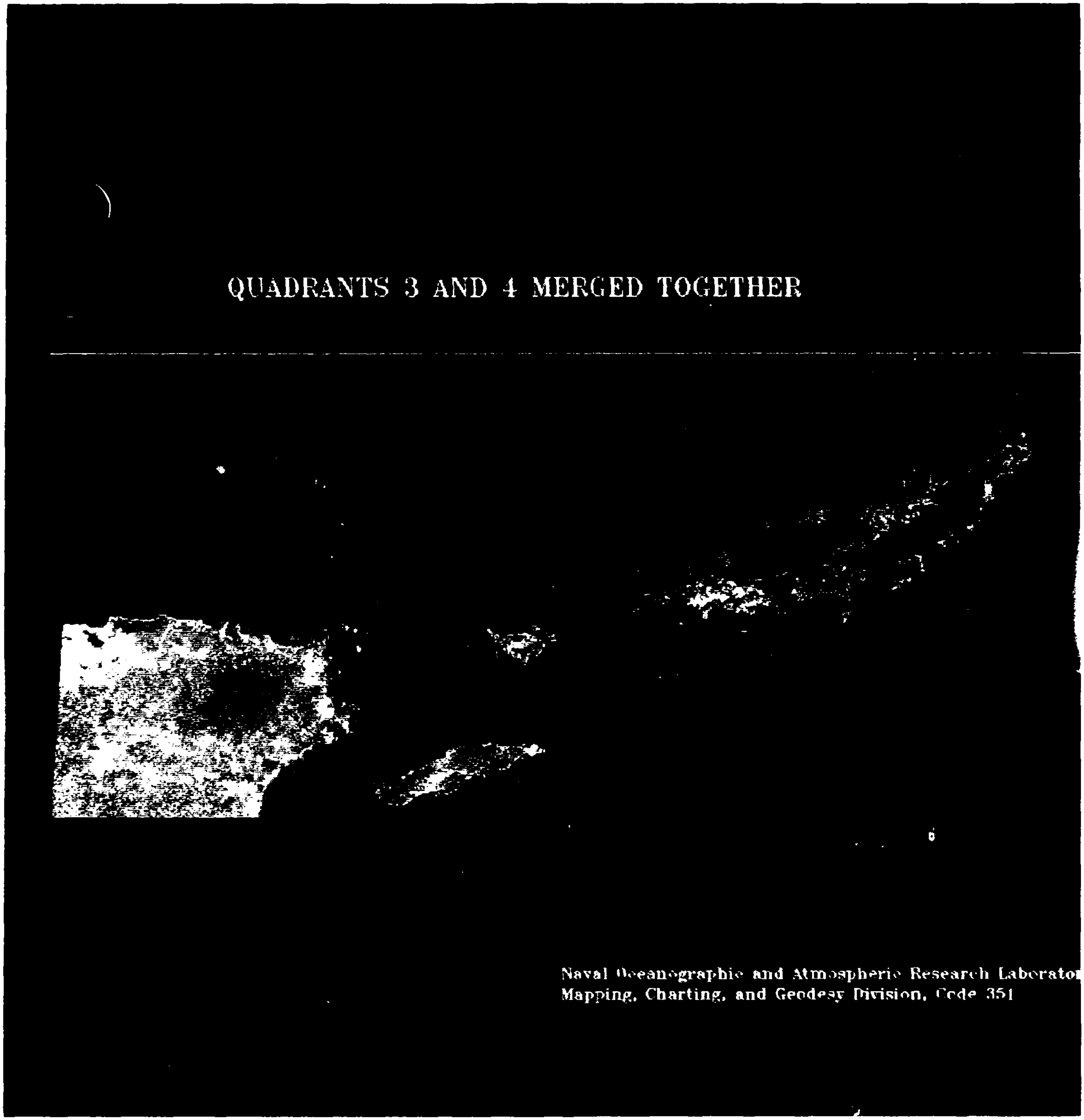


Figure 2. Quadrants 3 and 4 merged together

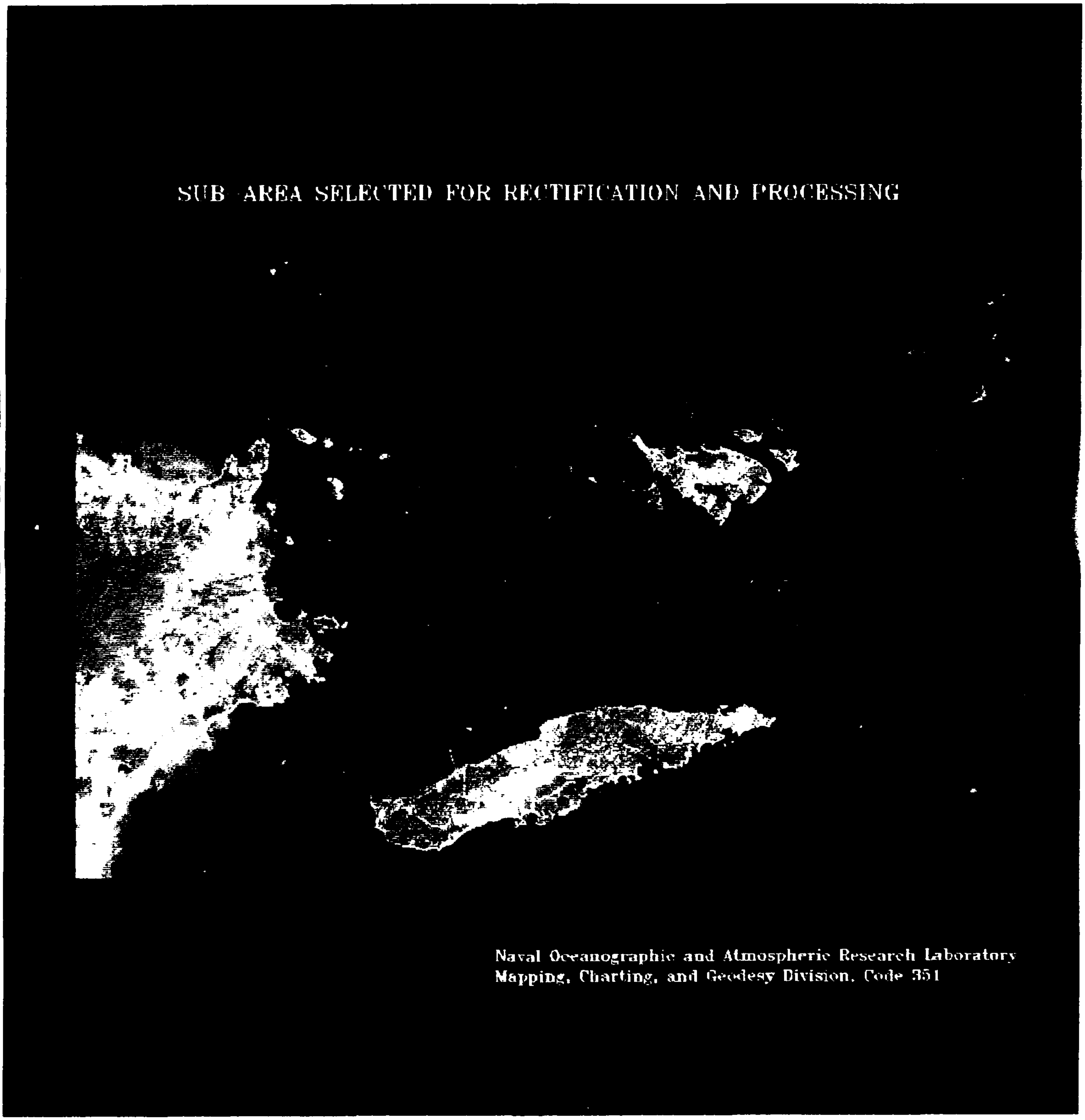


Figure 3. Sub-area selected for rectification and processing

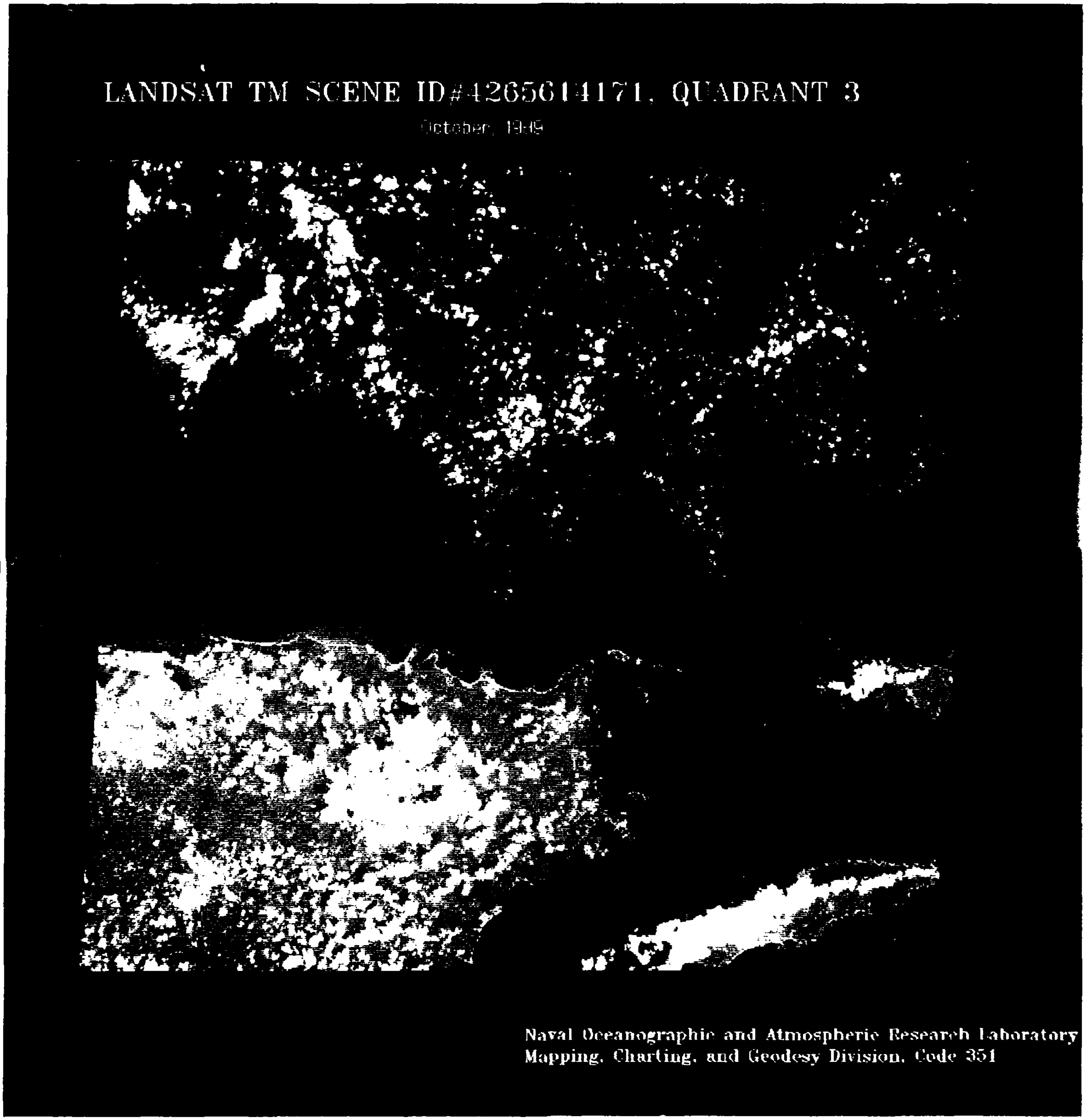


Figure 4a. Landsat TM scene ID#4265614171 quadrant 3, October 1989

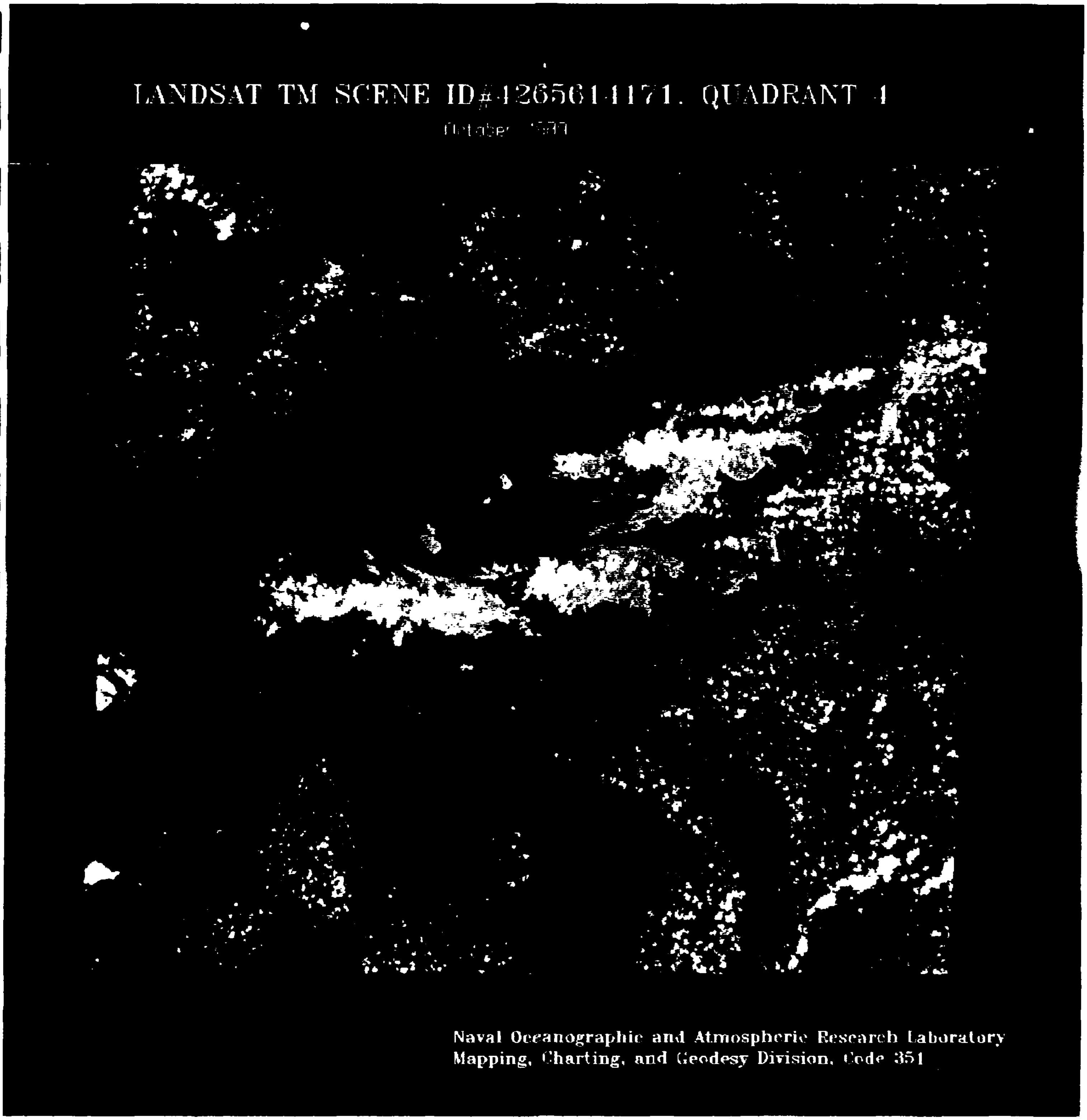


Figure 4b. Landsat TM scene ID#4265614171 quadrant 4, October 1989

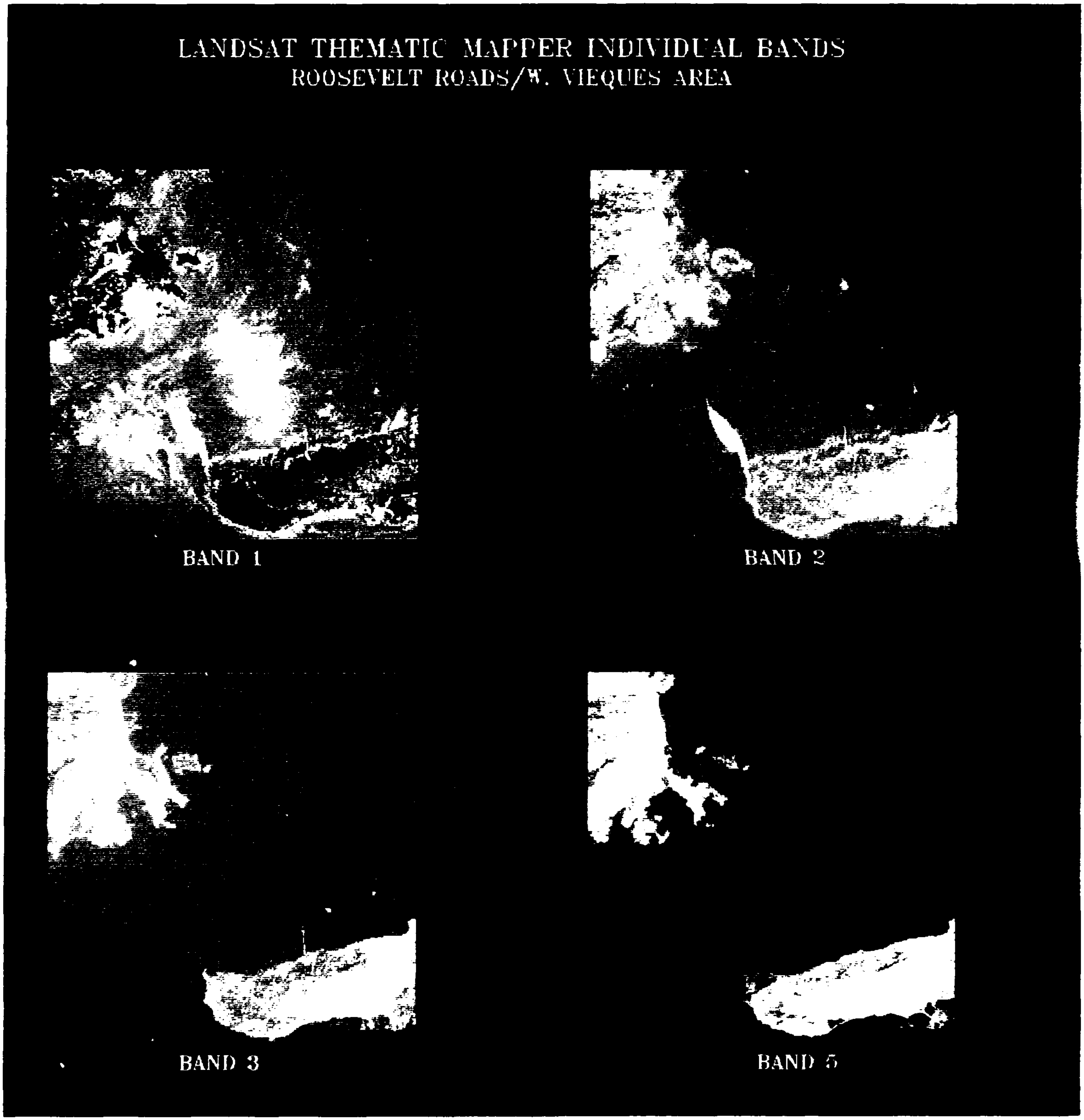


Figure 5. TM Bands 1, 2, 3, and 5 (monochrome)

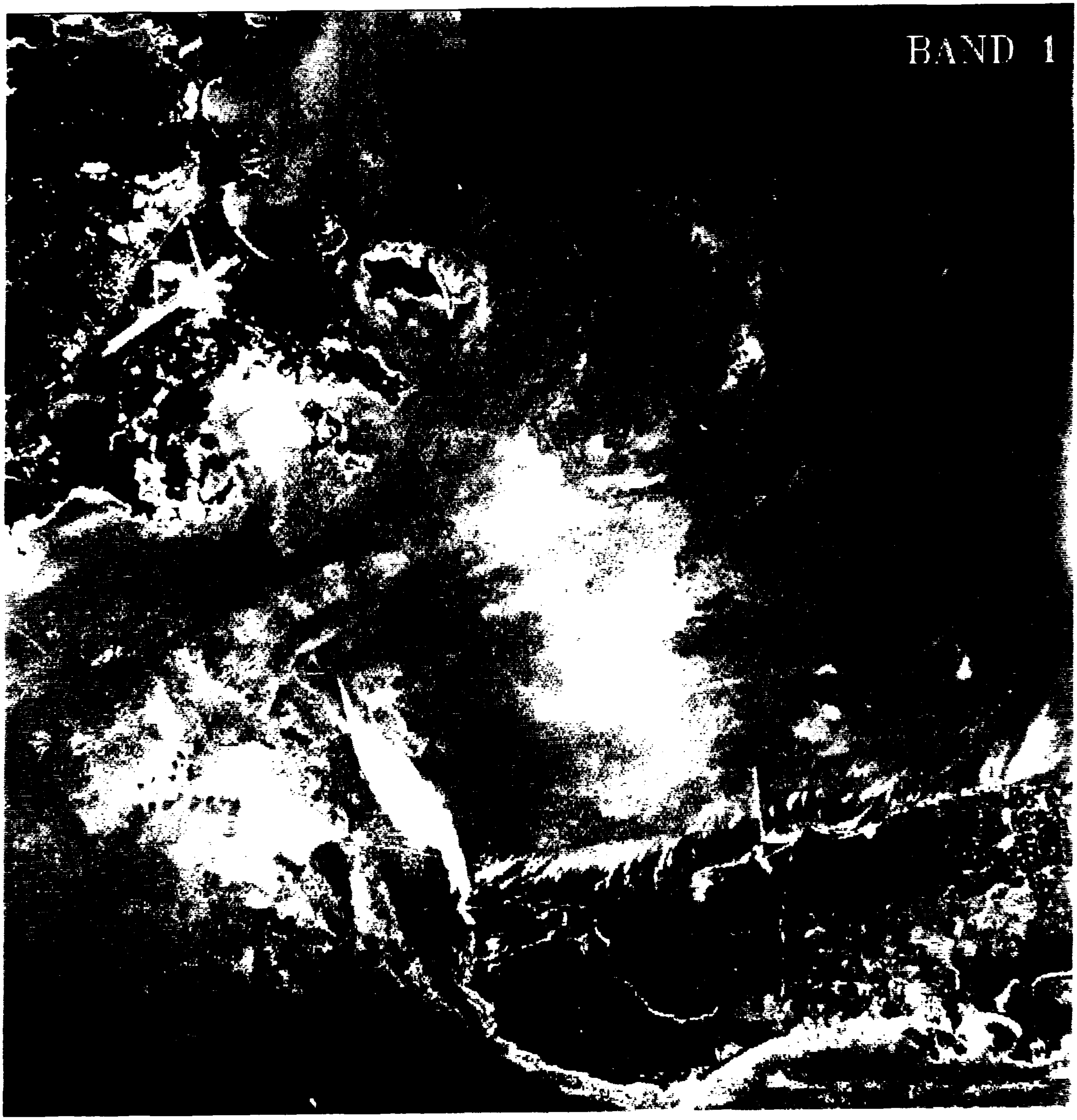


Figure 5a. TM Band 1 (monochome)

Figure 5b. TM Band 2 (monochome)

Figure 5c. TM Band 3 (monochome)

Figure 5d. TM Band 5 (monochome)

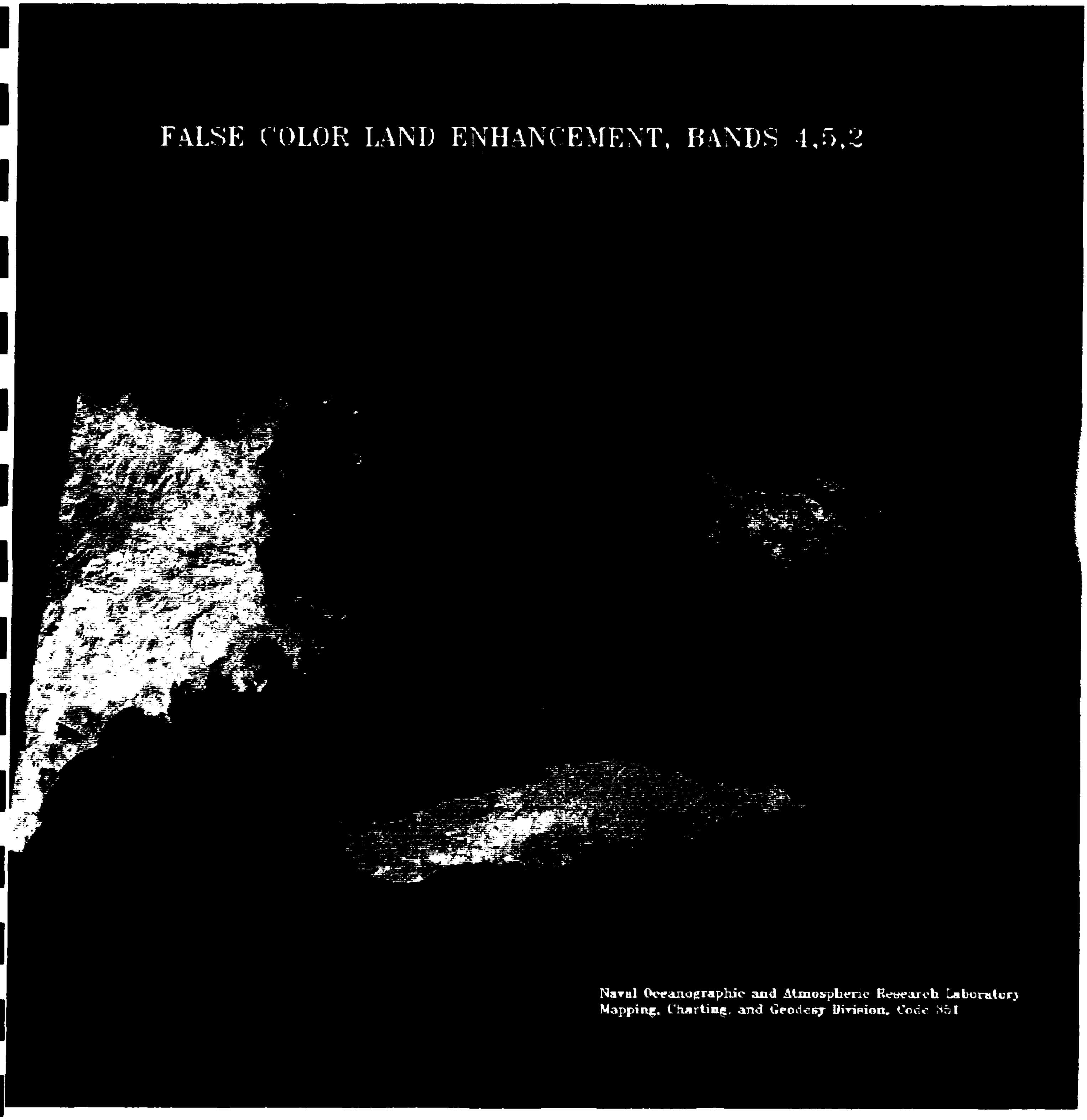


Figure 6. False color land enhancement, TM bands 4,5,2:R,G,B

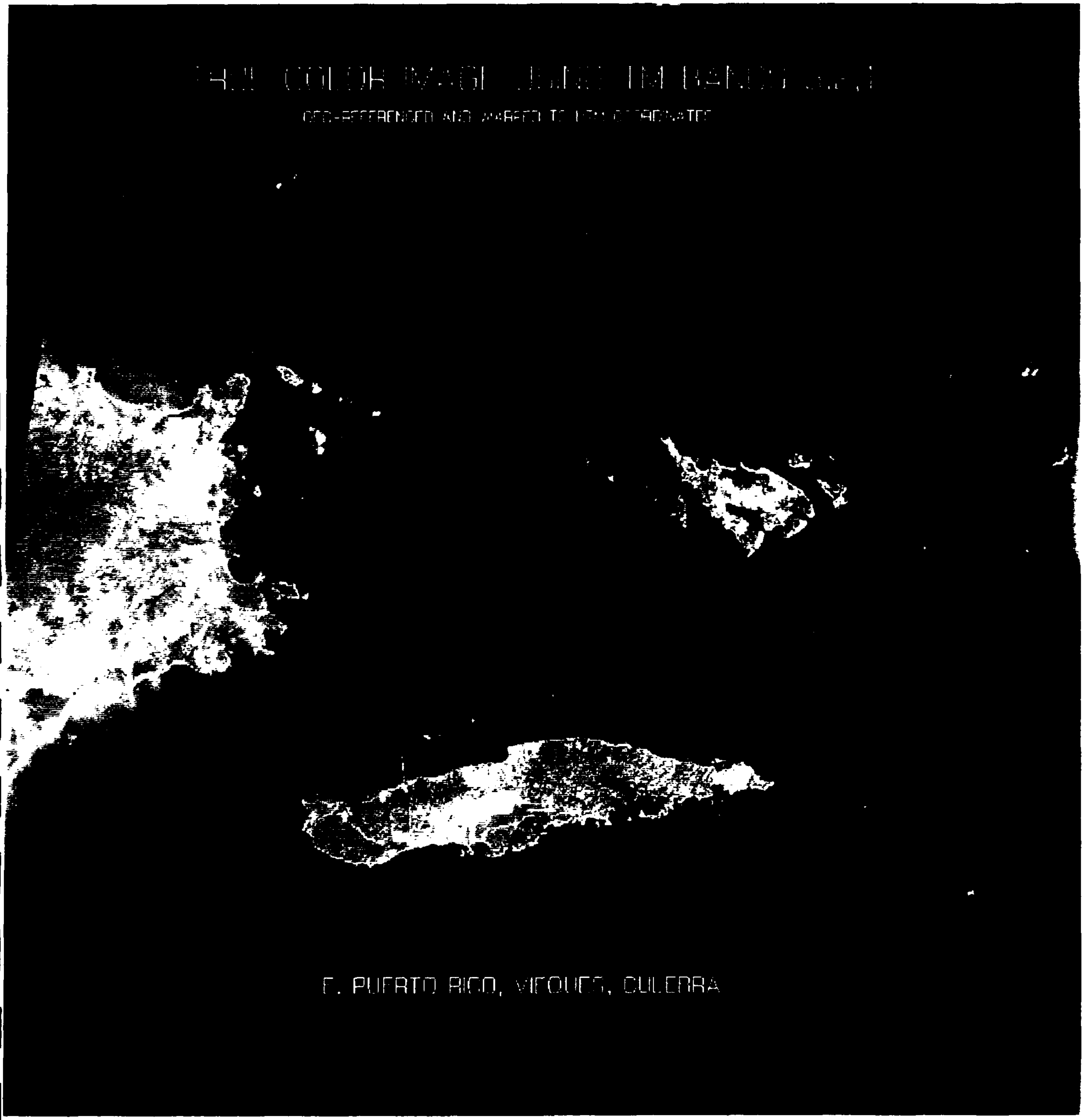


Figure 7. True color image using TM Bands 3,2,1:R,G,B. Georeferenced and Rectified to UTM coordinates

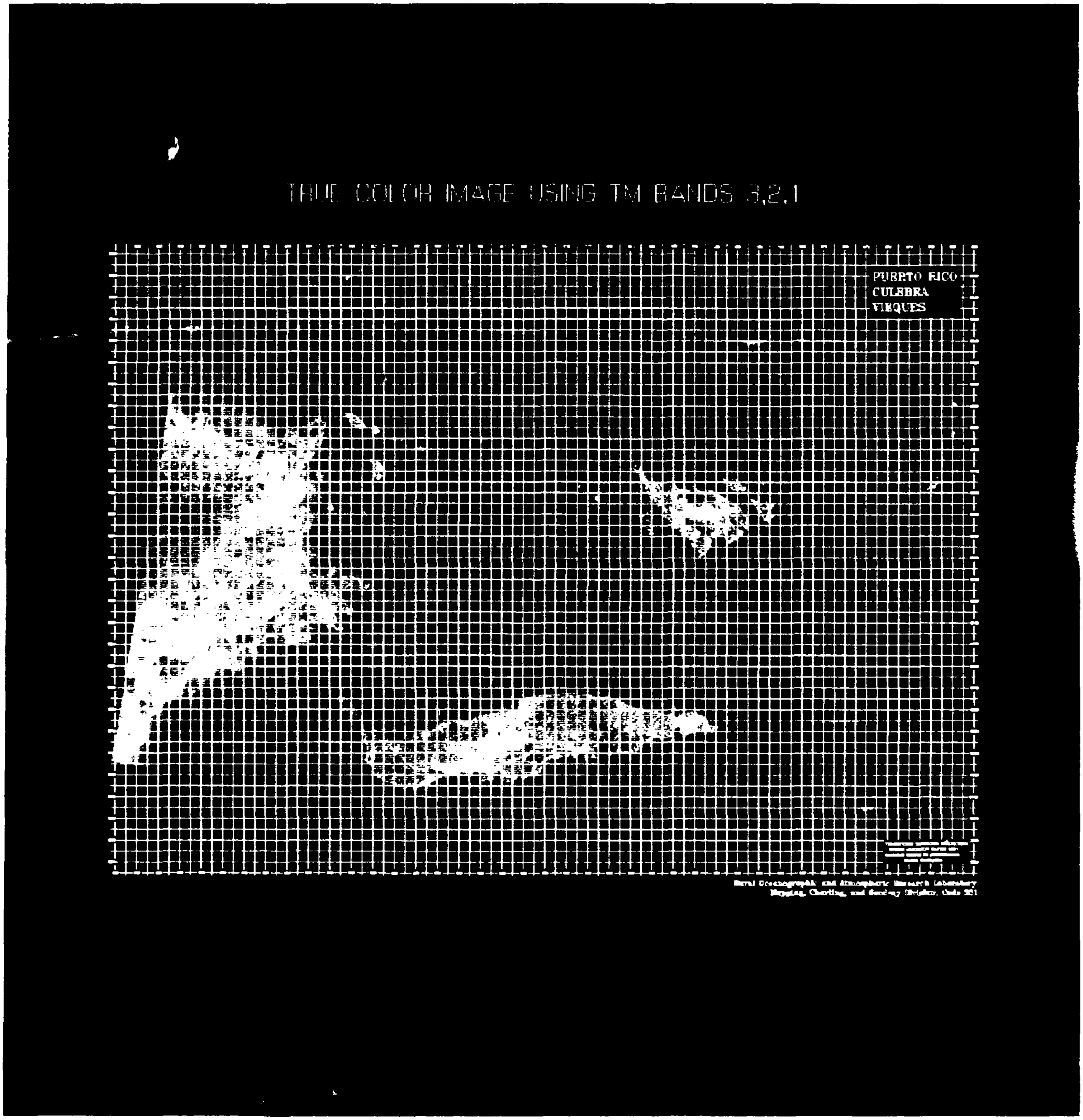


Figure 8. UTM coordinate grid lines on Georeferenced. Rectified image

Figure 9. Bathymetry calculated from 3-band regression model (land masked)

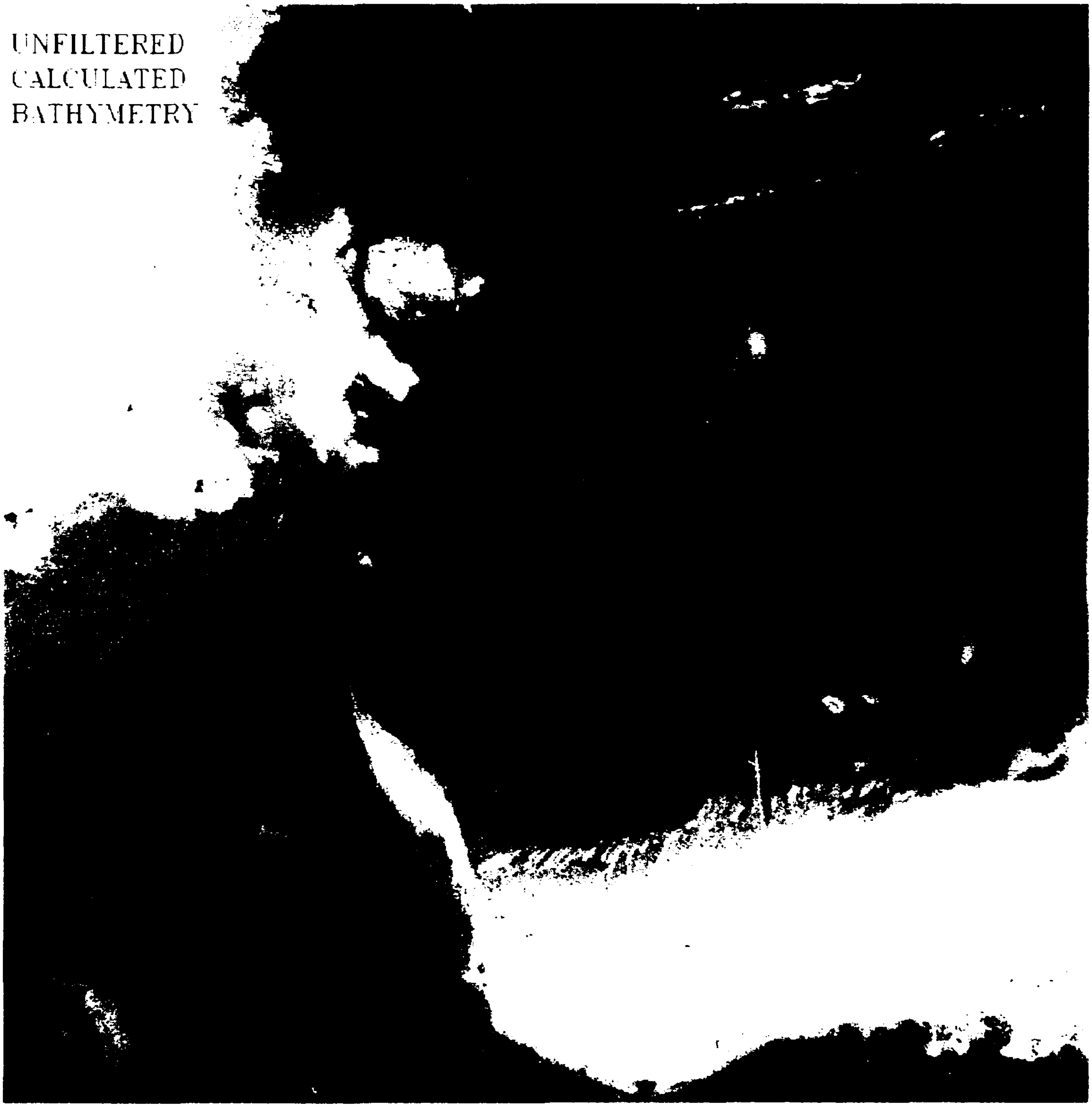


Figure 9a. Bathymetry calculated from 3-band regression model (full resolution, unfiltered)

Figure 9b. Bathymetry calculated from 3-band regression model (full resolution, filtered, 3 x 3 window, SNN, median value)

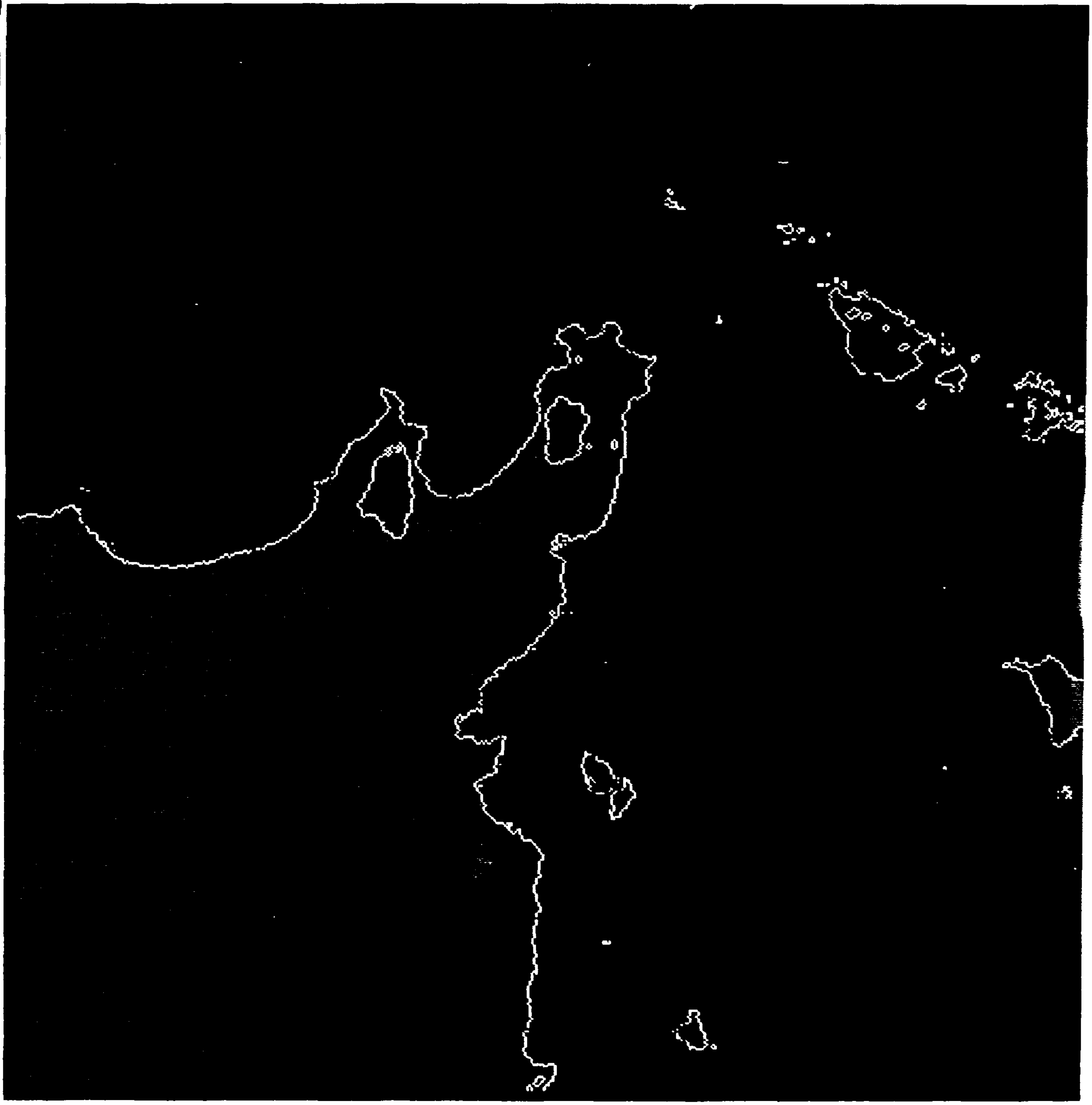


Figure 10.   Land/Water interface from TM band 5

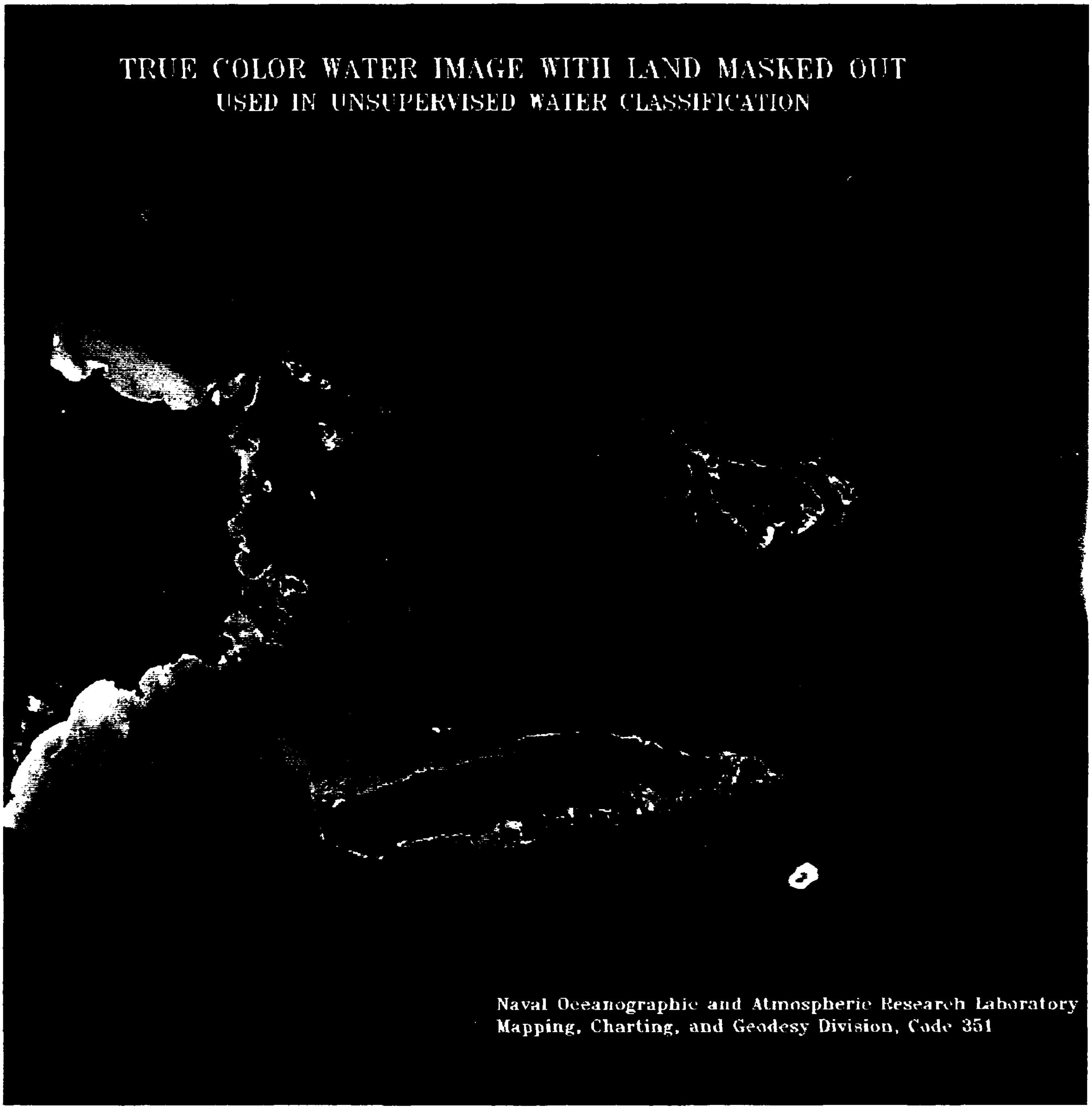


Figure 11. True color water image with land masked out (used in bathymetry calculations and water classifications)

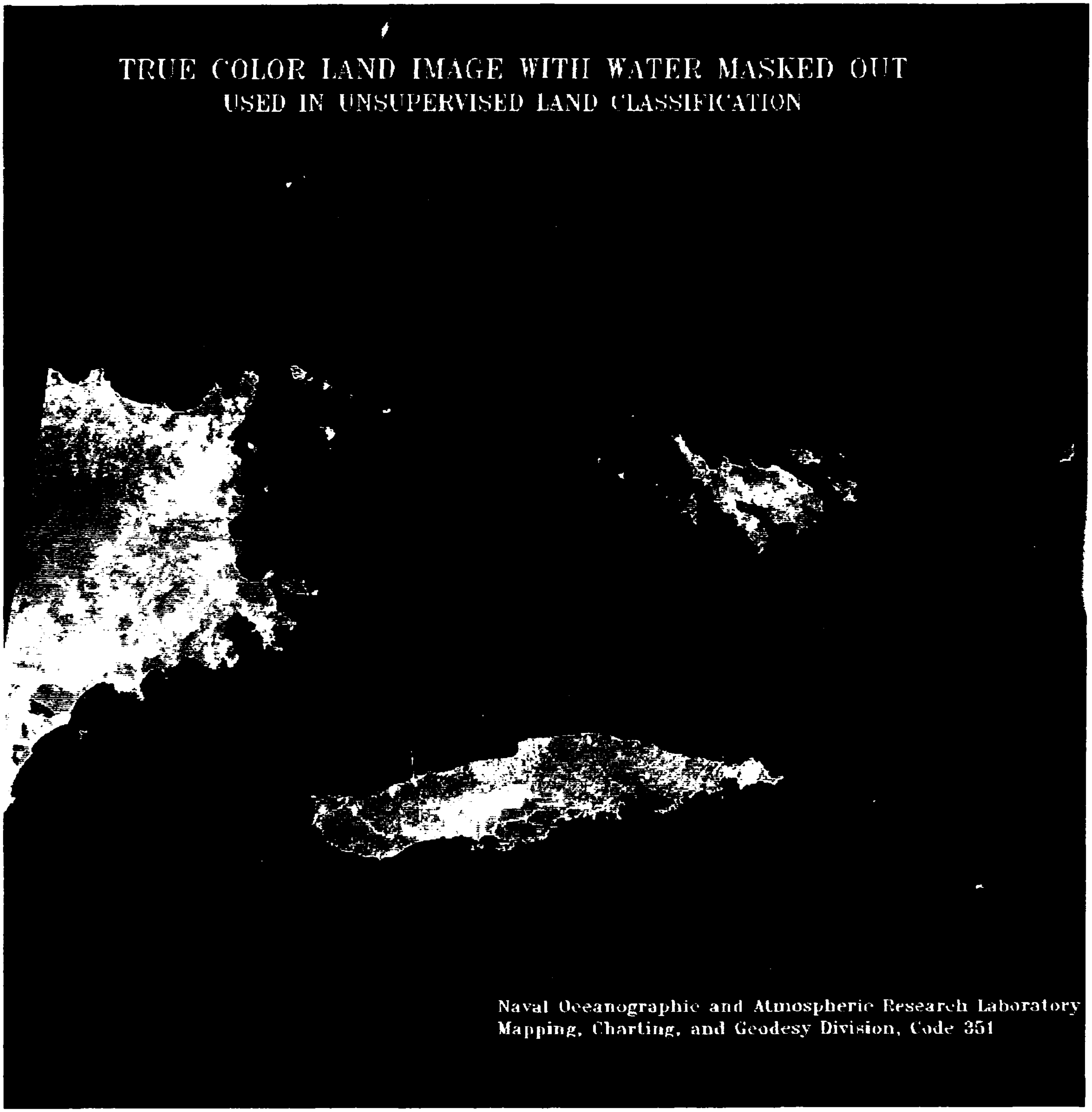


Figure 12. True color land image with water masked out (used in unsupervised land classification)

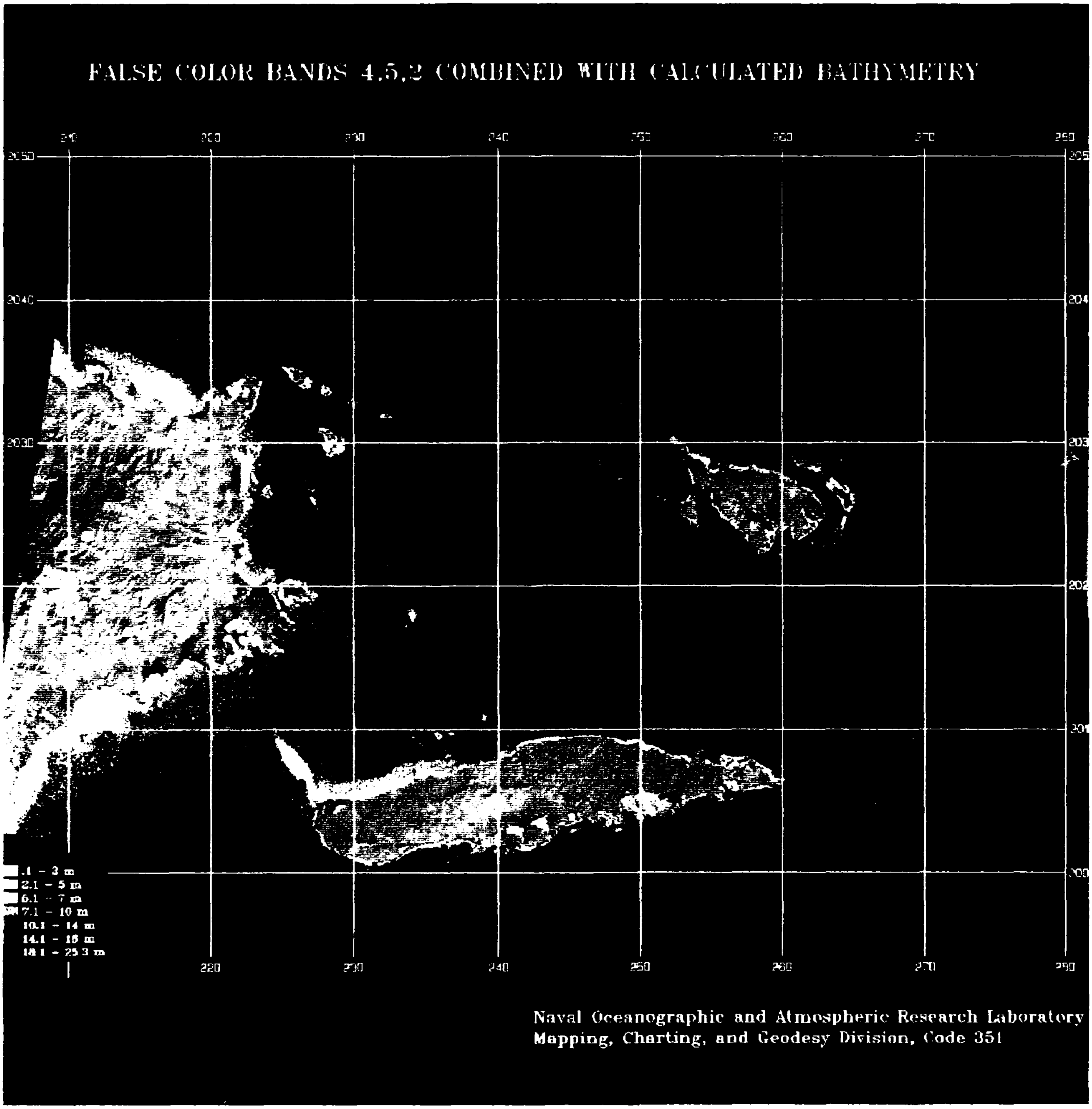
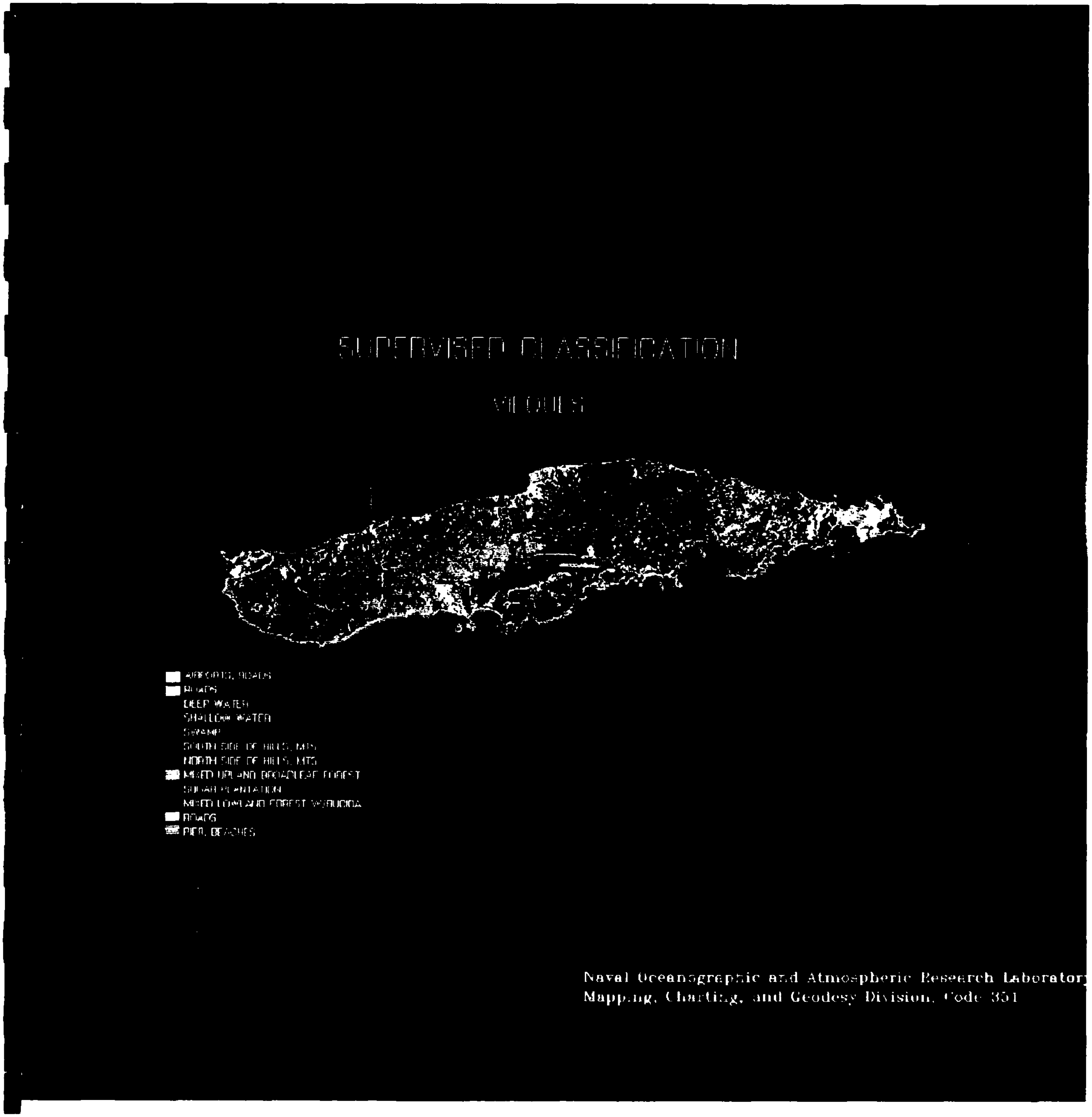


Figure 13. Combination: False color (band 4,5,2:R,G,B) land and calculated bathymetry water



14.Supervised classification using TM bands 1,2,3,4,5,7

Figure 15. Unsupervised classification (land only) using 6 TM bands: 14 Classes

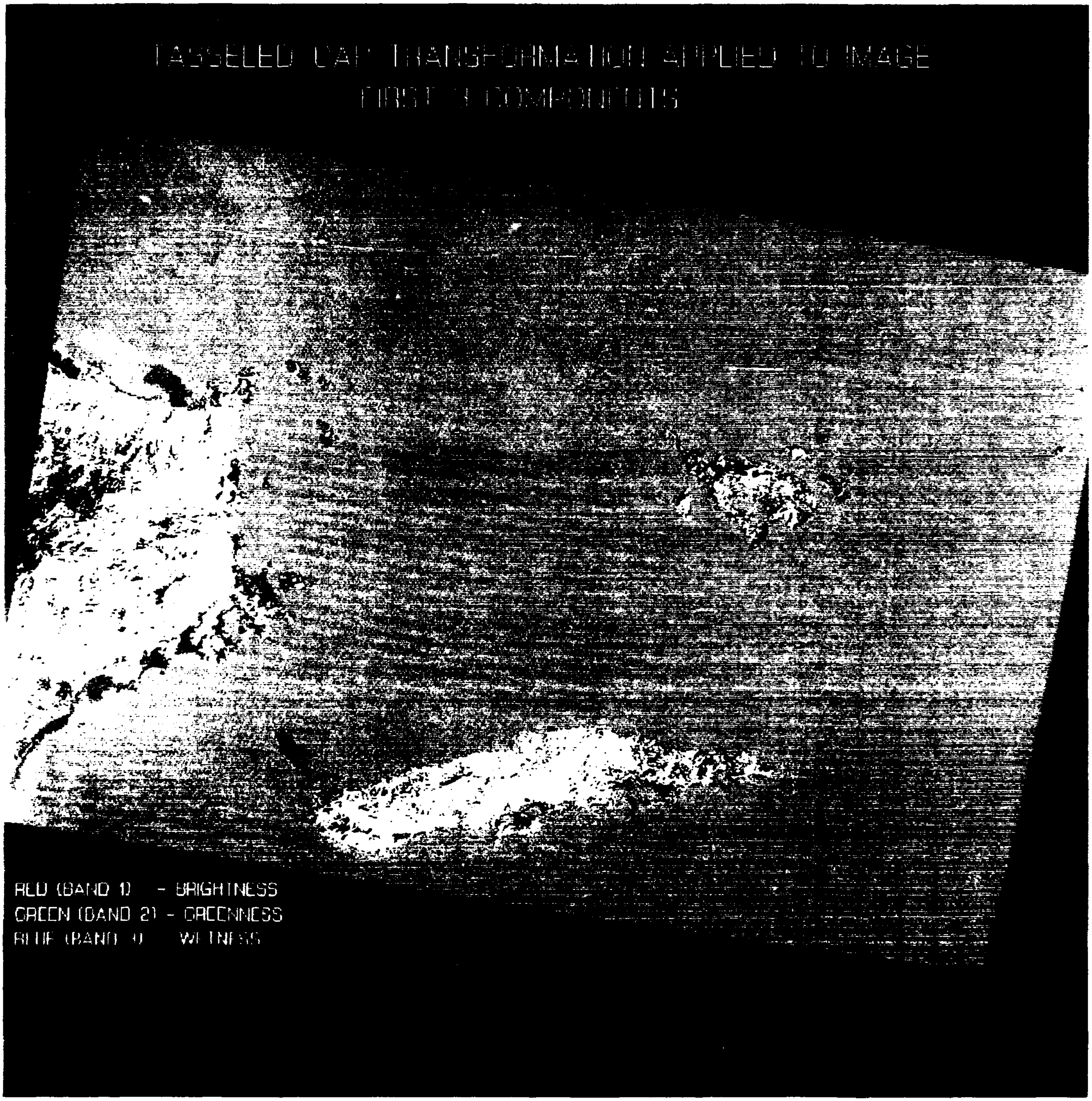


Figure 16. Result of Tasseled Cap transformation (components 1,2,3 : R,G,B)

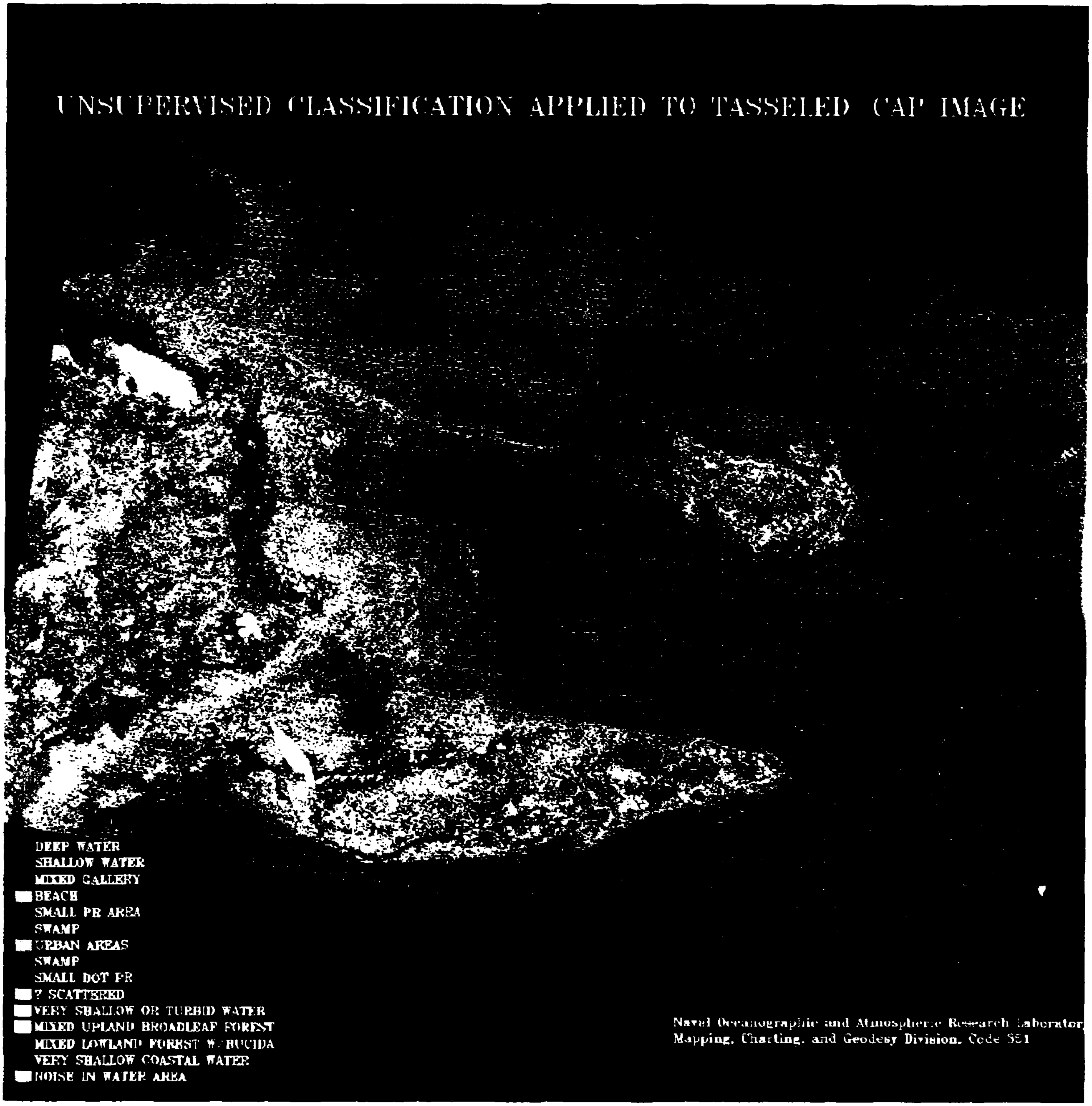


Figure 17. Unsupervised classification applied to 6 band Tasseled Cap Image

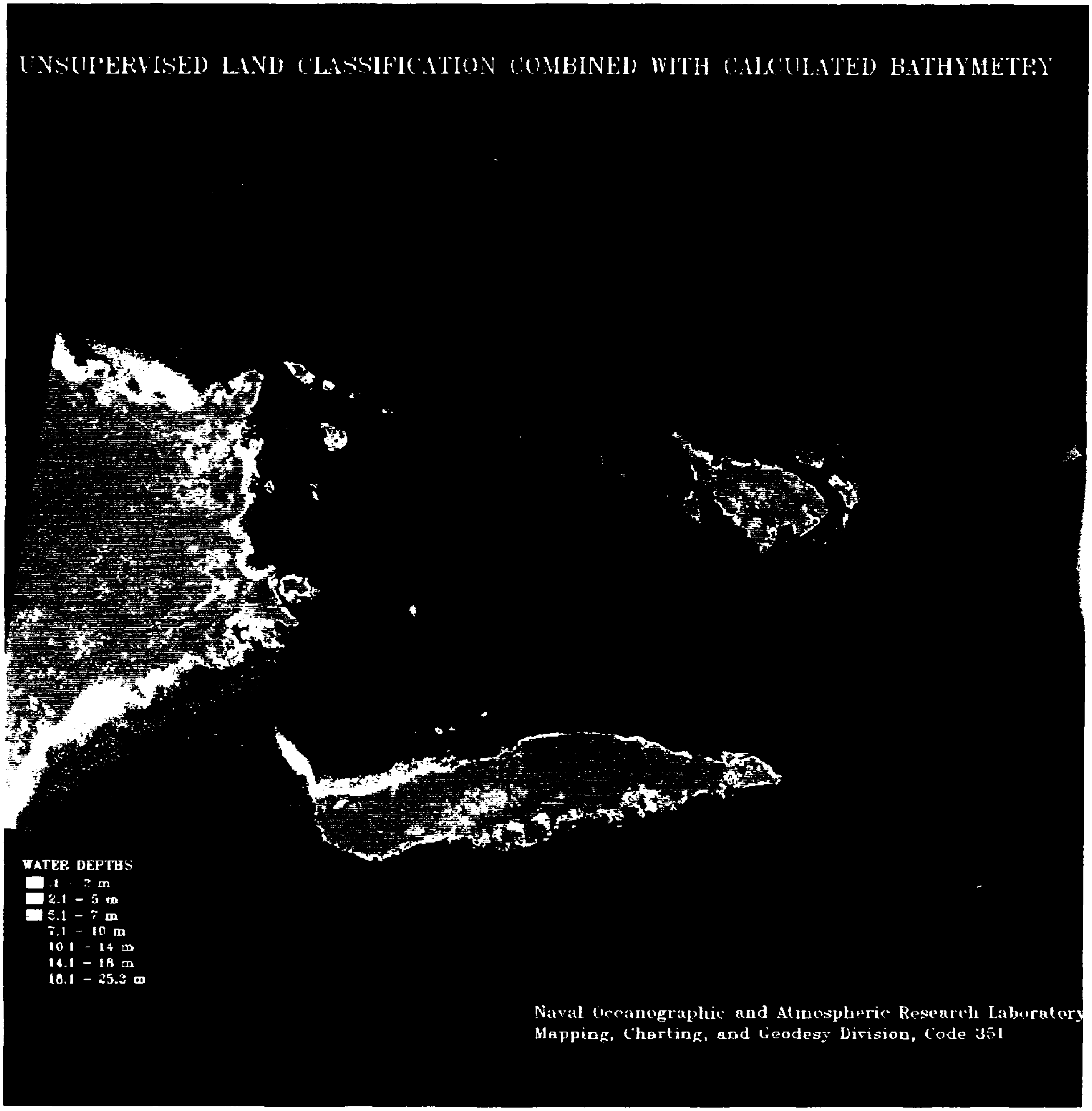


Figure 18. Combination: Smoothed bathymetry and Pseudocolor land classes (6-band, Unsupervised)

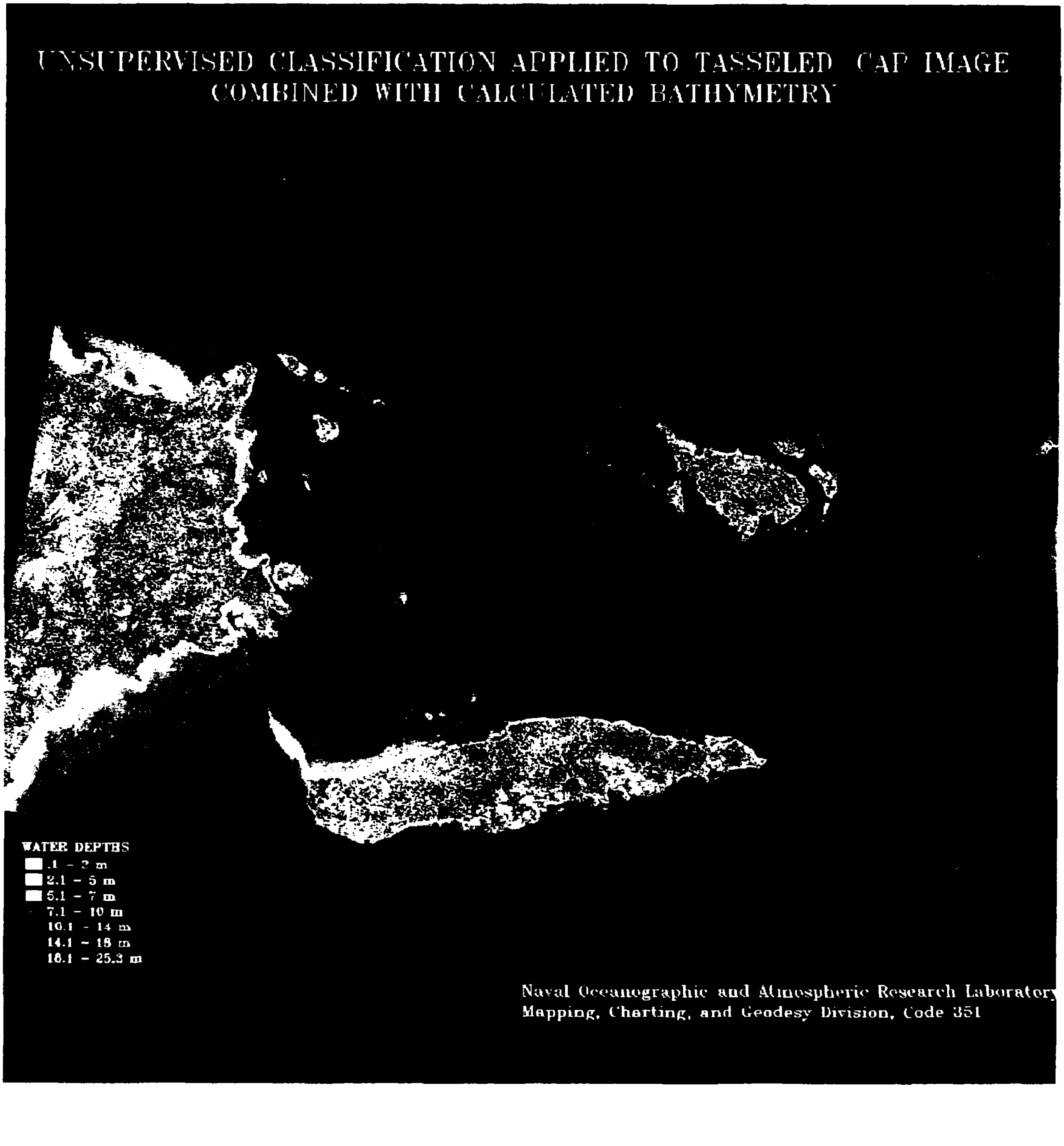


Figure 19. Combination: Smoothed bathymetry and Pseudocolor land classes (6-band Tasseled Cap, Unsupervised)

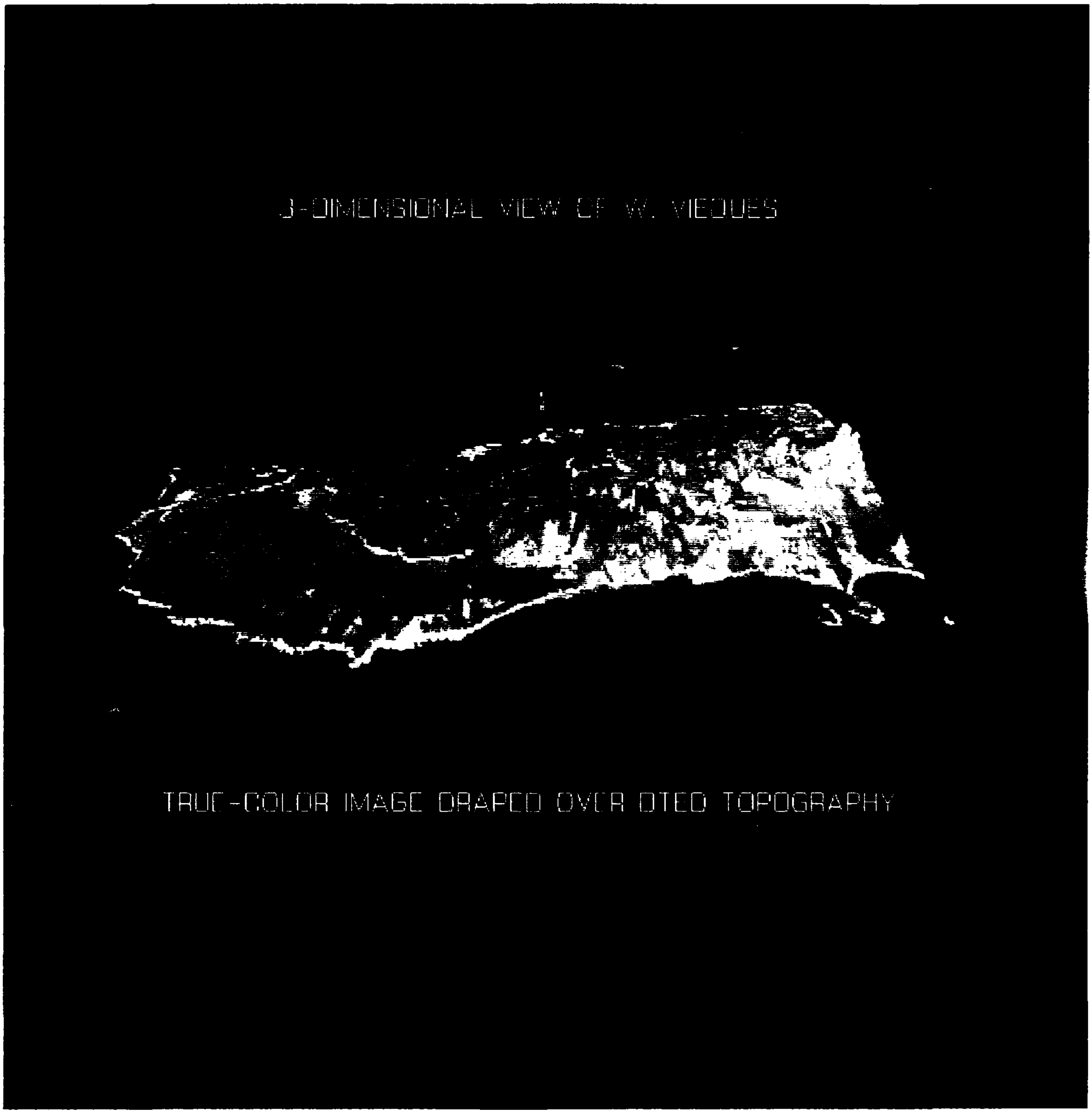


Figure 20. 3-D perspective view

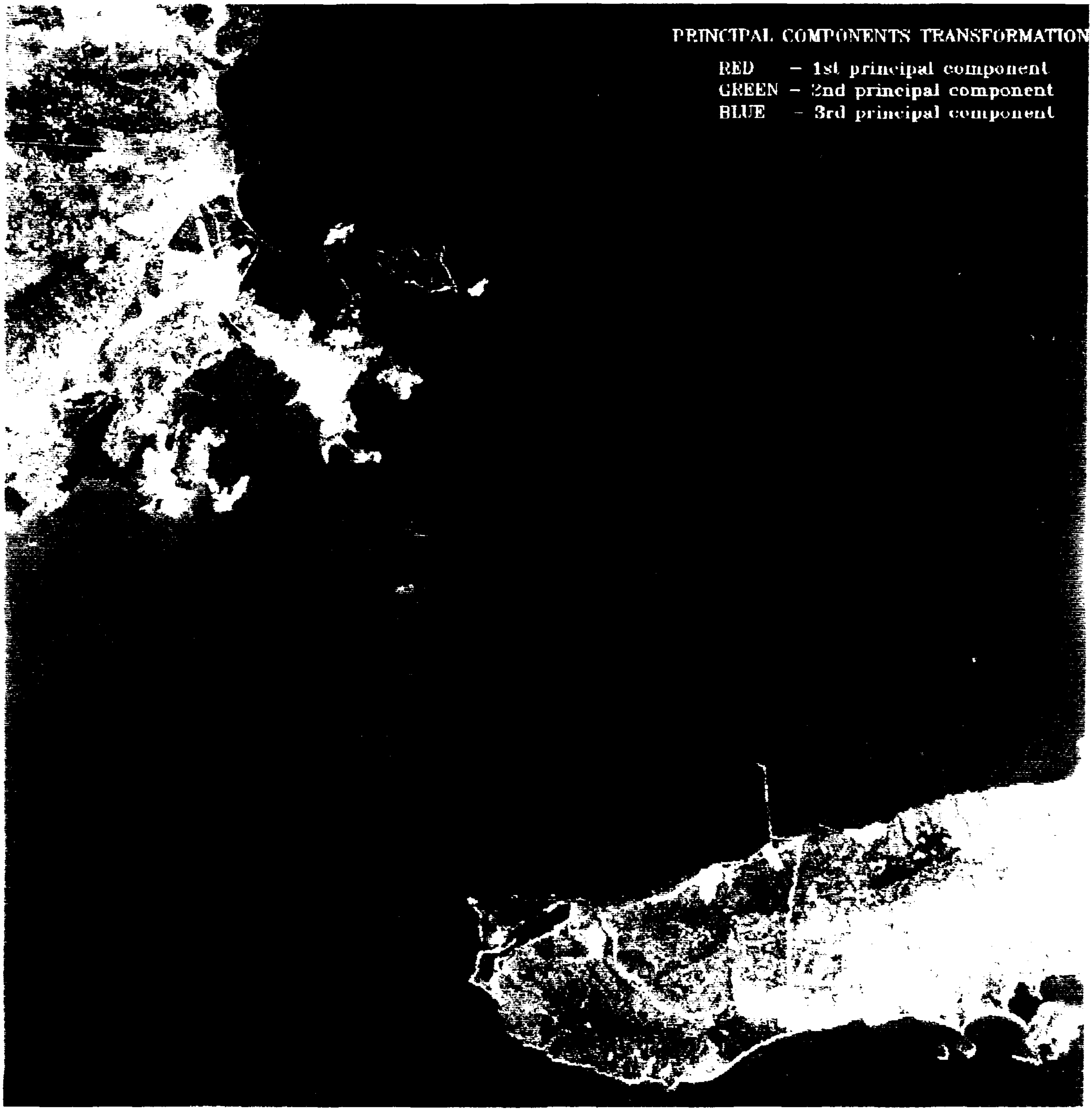


Figure 21. Principal component transformation (6-Band, components 1,2,3 : R,G,B)

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The Naval Oceanographic and Atmospheric Research Laboratory's Mapping, Charting and Geodesy Division performs research and development in new and improved methods for gathering navigational bathymetric data in coastal areas. One area of special interest is the development of algorithms to derive bathymetry from multispectral data. Currently, multispectral imagery can be derived from airborne scanners or from satellite sensors, such as the thematic mapper on board Landsat. Multispectral bathymetry has the potential for gathering data much more rapidly that present shipboard systems; in particular, satellite systems can gather data from many parts of the world that are denied to other collection systems. This report presents the results of applying multispectral bathymetry algorithms and image enhancement and classification techniques developed at NOARL to support a joint amphibious exercise.

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